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Assessment of Skill and Performance in Flying

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ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

ASSESSMENT OF SKILL

AND

PERFORMANCE IN FLYING

Proceedings of the Twenty-third Annual Meeting of the AGARD
Aerospace Medical Panel held in Toronto, Canada, 7th September, 1966

FOREWORD

This volume contains 13 papers of the programme of the Twenty-third Annual Meeting of the Aerospace Medical Panel of the NATO Advisory Group for Aerospace Research and Development, held at the Defence Research Medical Laboratories, Toronto, Canada, on 7th September 1966.

All opinions expressed are those of the respective authors and do not constitute AGARD or NATO policy. Each senior author assumed the responsibility of editing his own paper.

The programme was divided into three technical sessions, each covering a general subject area, as shown in the Table of Contents.

All papers were given in English. Original abstracts were translated by Miss Monique Dubois (English to French).

Publication of these collected papers was authorized by the Editorial Committee of the AGARD Aerospace Medical Panel.

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HUMAN ERROR RESEARCH AND ANALYSIS PROGRAM

(HERAP)

by

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SUMMARY

In 1964 a proposal was made by a representative of the US Naval Aviation Safety Center to the annual meeting of the Navy Air Board that a long term study of human error accidents be undertaken. As a result the Human Error Research and Analysis Program (HERAP) was implemented.

The proportion of Naval aviation accidents attributable to human error for several years has exceeded that attributed to equipment malfunction or failure. The reasons for the high ratio of human error caused accidents are varied and in many cases obscure. If Naval aviation is to continue accident reduction, it is apparent that human error must receive increased attention. HERAP is designed with this purpose in mind and represents the first long term longitudinal study from the systems analysis approach.

In February 1966, Douglas Aircraft Company prepared a HERAP report which describes the problem ramifications, parameters and recommended methodology for a study in depth. The continuation of this study is being undertaken at present on a contract basis until the US Naval Aviation Safety Center develops the in-house capability to conduct the problem.

For the AGARD Aerospace Medical Panel a proposal is made to describe HERAP in detail.

RESUME

A l'occasion de la réunion annuelle de la Commission Aérienne de la Marine en 1964, un représentant du Centre de Sécurité de l'Aéronavale des Etats Unis proposa que soit entreprise une étude à long terme sur les accidents dûs à l'erreur humaine. C'est à la suite de cette proposition que fut mis sur pied le Programme de Recherche et d'Analyse de l'Erreur Humaine (HERAP).

Despuis plusieurs années, la proportion d'accidents frappant les appareils de l'Aéronavale et imputables à l'erreur humaine est supérieure à celle des accidents attribuables à un mauvais fonctionnement ou une défaillance mécaniques. Les raisons en sont variées et, dans de nombreux cas, obscures. Si l'Aéronavale veut poursuivre sa politique de réduction des accidents, il est évident qu'une attention accrue doit être consacrée au problème de l'erreur humaine. C'est le but poursuivi par le HERAP, qui constitue la première étude longitudinale à long terme envisagée du point de vue de l'analyse des systèmes.

En Février 1966, la Compagnie Douglas Aircraft a préparé, dans le cadre de l'HERAP, un rapport qui expose le problème, ses ramifications, les paramètres impliqués, et les méthodes recommandées pour une étude en profondeur. Cette étude est actuellement menée sur la base de contrats jusqu'à ce que le Centre de Sécurité de l'Aéronavale US ait mis au point ses moyens propres afin de poursuivre elle-même le programme entrepris.

Il est proposé de donner au Groupe de Travail de Médecine Aérospatiale de l'AGARD une description détaillée du HERAP.

HUMAN ERROR RESEARCH AND ANALYSIS PROGRAM (HERAP)

Captain R.E. Luehrs, MC, USN

1. INTRODUCTION

The objective of the Naval Aviation Safety Center is to contribute to the maintenance of the operational readiness of the Navy at the highest possible level by reducing the losses in lives and aircraft which are sustained in the course of the Navy's world-wide air operations. Much has been achieved in pursuit of this objective during the past several years, but at the present time a plateau seems to have reached. One of the most cogent problems facing the Naval Aviation Safety Center today is concerned with human error involved in aircraft accidents.

2. DISCUSSION

2.1 What is HERAP?

HERAP is an accident prevention research program for the purpose of investigating the nature and extent of human error in aircraft accidents.

In recent years, numerous attempts have been made to delineate man's capabilities to perform a variety of tasks in aviation. These include cross-sectional statistical and case history studies in which man's adaptation to the airplane and the environment have been explored. There has not been a systematic approach to the problem of human failure in the man/machine environment complex of naval aviation until recently.

The ground work for such an approach began in June, 1964, when a representative of the Safety Center presented to the annual meeting of the Navy Air Board a plan for a program which would intensely study human error with the ultimate goal being a further reduction in the aircraft accident rate. The Board concurred with this proposal and directed the Naval Aviation Safety Center to undertake this study. The study was given the name "Human Error Research and Analysis Program" or HERAP.

HERAP is envisioned as a longitudinal study of 20 years' duration which is and will be conducted by contract until the Safety Center develops the in-house capability to assume the program. The first phase of the study was completed in February, 1966, by Douglas Aircraft Company. This consists of a document which describes the problem and its parameters in detail and outlines a methodology fo studying it in depth.

This initial phase of HERAP was to define a long-term accident prevention program which has as its objective to reduce accidents caused by human error and to specify the required procedures of its implementation. The proposed strategy for defining a long-term effort involved building a program upon the current work of the Naval Aviation Safety Center and structuring it toward the achievement of long and short term goals.

Goals of the long range program were originally defined as follows:

(i) To develop an appropriate and operationally feasible reporting procedure.

(ii) To develop a data bank having the capabilities and characteristics for:

(a) data categorization, storage and retrieval,

(b) calculation of frequency distributions with categories,

(c) storage of longitudinal profiles of personnel,

(d) statistical analysis of data,

(e) generation and testing of hypotheses in the data,

(f) upgrading the data bank both continuously and periodically,

(iii) Flexibility, allowing adaptation to changes in equipment, personnel, and knowledge.

(iv) Direct application to the Fleet.

(v) Coordination with experimental efforts in connection with location of accident causes.

2.2 What is Human Error?

Human error may be defined as "the specified deviation of human activity or decision from an operationally defined norm." It is essential that we agree upon a working definition, at least, of what human error is before undertaking a long-range accident prevention program. This definition suggests that error cannot occur unless limits have been set before accidents happen.

One of our major jobs is to determine these limits and record, manipulate, and act upon data in a meaningful way within this frame-work. It is suggested that in Naval aviation there are many circumstances where it is perfectly clear that the human operator had no chance to mitigate or even influence the result.

All human beings have limitations; the human organism is not infallible; it is far from perfect. As the amount and complexity of flying increases, human error becomes more apparent. The human errors attributed to aircraft accidents center around proneness to forget; to display bad judgment; to become confused and exhibit poor technique; to evidence slow reaction time; to distort visual and auditory perception, and to exhibit other manifestations of human limitations.

Our approach must examine these limitations and attempt to specify what we expect of our human operators and what characteristics they must possess in order to carry out tasks in specific systems. We shall look at "error" from the point of view of a deviation from what can be expected, but shall not necessarily attach blame to the individual for the deviation. Our attack will be to attempt to predict performance of the specific task, having determined the nature of the task carefully from the point of view of what qualities, at what levels, and with what variability are required by it for a specified performance.

2.3 A Systematic Approach to the Study of Human Error in Naval Aviation Safety.

By a systematic approach is meant a methodology for studying and analysing the accident-producing system. The proposed systematic approach, or methodology, involves mathematical modeling techniques and statistical estimation of the parameters in the system. Mathematical models and computerized techniques have proved to be very useful in more sophisticated approaches to a better understanding of the man/machine relationship.

The system here is a very complex one. It consists of a man/machine subsystem interacting with various elements of the environment. Such a system is not easy to deal with. The subsystems are each complicated enough but, when they interact, the problem could become horrendous. Other kinds of error in the system cannot be overlooked, but the focus here shall be on human error.

Only a model, or a master plan, for a systematic approach to the problem can be presented. There are many facets of the problem that are unknown. Many years of research will be required before the statistical parameters involved in the mathematical model can be adequately estimated.

In systematizing an approach to the relation of human error to aviation accidents, the 4 M's structure shall be adopted. This structuring of aviation accidents and human error involves a triadic relation of the relata: (1) *man;* (2) *machine;* and (3) *media* (i.e., the environment of one and two) in which one must (4) *manage* two in the "context" of three. Here the term management shall be construed to mean the effective control by a human of the machine with which he is required to interact. In this case, the machine would be an aircraft or one of its subsystems. There are several noteworthy implications of the 4 M's structure: First, the two interacting systems (i.e., man and machine) could collectively or separately be characterized by a *systems effectiveness* measure which essentially describes performance; secondly, the effects, if any, of the immediate operating environment upon the effectiveness with which man manages a given machine, as well as the effectiveness with which the machine remains within the limits of tolerable performance, must also be considered; finally, in order to have variables that are both observable and measurable, it would seem best to define tolerable performance limits for both man and machine in terms of effective task accomplishment. Thus, a machine performs within tolerance if, and only if, it accomplishes the set of tasks for which it was designed. For a trainable "machine" such as man, one must add that he performs within tolerance if, and only if, he accomplishes at the proper time the tasks for which he was trained. Here, the term training may be interpreted as both highly structured as well as relatively unstructured past experience.

In order to accurately describe human error with the frame-work of the 4 M's structure, a measure of performance which adequately relates degraded performance and error is needed.

This system effectiveness measure can characterize all sub-systems, collectively or separately.

The effectiveness measure considers tolerance performance limits for all components of the system in terms of effective task accomplishment. The measure presupposes system states, describable in terms of some degraded mode of performance, which produce a certain amount of error. This error is referred to as "error in a critical system parameter."

The mathematical evaluation of the measure involves some rather formidable concepts.

It should be recognized that the meaning of "system state" is not restricted to that of a single performance mode, but may also indicate combinations and/or sequences of performance modes. Thus, it would seem that for the human biological system, in its relation to aircraft accidents, three very general performance modes are basic:

- o Degradation in reaction time,
- o Degradation in tolerance thresholds,
- o Degradation in accuracy of judgment,
  - Visual and auditory perception,
  - Choice discrimination,
  - Observation,
  - Decision making,
  - Data handling,
  - Skills and techniques.

There are, perhaps, other basic modes and undoubtedly there are further subdivisions of the three modes presented here.

2.4 Some Basic Considerations in HERAP

The approach to the problem will be multi-disciplinary, utlizing current and future statistical tools, including computers. As a starting point, data from the Safety Center files will be blended with data from analyses of human characteristic and capability analysis, aircraft construction and configuration, mission profile and performance and operational environment. This will constitute the basic data bank. Data will be acquired and categorized by standard methods and stored in easily retrievable form. Trends developed by data analysis will be explored in detail as priority dictates.

A mission analysis will be done for each basis aircraft type in the inventory, for each modified version aircraft and for each type of mission profile. The latter will run the gamut from high altitute, high speed intercepts to those involving antisubmarine planes circling datum points at very low altitude above the sea surface day and night. These analyses will be in great detail, considering every phase including pre- and post-flight periods. An early step consists of establishing matrices of various sorts, meshing them to find specific data points and placing this material in the data bank. The bank is to be constructed so that information can be added or retrieved rapidly.

Information from the fleet and shore activities will be collected, screened, validated and stored, and, as practices and hardware change, updating will ensue.

HERAP must consider the training sequence of pilots and other Naval personnel involved in the accident-producing system. This is true for several reasons. One obvious reason is that training affects the level of skill attained for a specific task. Furthermore, training provides measures of proficiency which may be analyzed in relation to accident hazard.

Training in Naval aviation is no longer dependent entirely on the ideas of the instructors. Training in Naval aviation has now progressed into very complex ordered systems (with considerable disorder in some of the sub-systems). Furthermore, both formal and informal training continues throughout the life of the aviator as it does in other professions.

Many specific investigations will emerge within the framework of the systems approach. The various specific investigations will involve an interdisciplinary approach (biomedical, pathological, psychological, biophysical, statistical, engineering, etc.) but may be focused on a specific aspect of aircraft accidents. Some examples of immediate problems to be investigated are:

(a) Night carrier landings.

(b) Collision avoidance.

(c) Fatigue.

(d) Disorientation.

(e) Index of accident exposure.

2.5 Why Study Human Error?

Although Naval aviation is one of the more hazardous occupations, men continually, on a day-to-day basis, undertake to accomplish their mission successfully. Naval aviators fly *ten* thousand hours each day in a large number of different missions. An average of *0.7* lives of pilots and crew members combined are lost each day and the dollar cost in equipment loss is approximately $1,000,000. By today's standards, it is estimated that a Lieutenant Commander or Major Naval Aviator costs approximately $1,250,000 in terms of training investment. Even more costly to the accomplishment of the military mission is the 10 years which is required to replace such a man with one of equal experience. These are impersonal elements which in no way reflect the overall impact which such losses produce.

Over 60% of Naval/Marine aviation accidents have human error assigned as a causative or contributory factor. In industry, if a major problem exists in a particular area, then into that area go the talent and money necessary to rectify the situation. The Navy, more specifically the US Naval Aviation Safety Center in Norfolk, Virginia, likewise attempts to follow this good management principle and has recently begun to implement the Human Error Research and Analysis Program (HERAP).

In reviewing Naval aircraft accident statistics over the 20 year period of 1944 through 1964, certain trends are quite evident. There has been a definite decrease in the number of accidents per 10,000 hours of flight time and fewer fatalities accompany this trend. However, the cost per accident has risen steeply. Some factors which have produced the downward accident/fatality trend are: Better selection of student pilots, improved training, efforts to provide men/machine compatibility and the inculcation of the concept of aviation safety through the various command levels. Meanwhile, economic changes and increased complexity of military aircraft and systems have driven the cost per unit substantially upward. Illustration of this point is not difficult; in the 1940's, unit costs were in terms of thousands of dollars but in the present era, millions of dollars has become the common denominator of expression.

In evaluating our accidents there are four major categories into which they are placed. The largest group comes under the heading of *Pilot Cause Factor* which covers a broad list of acts of omission and commission. The next category in number is *materiel caused accidents*. In this group are those accidents which can be attributed to a breakdown in the aircraft or its systems.

The role of human error in these accidents must be overlooked. Design failure, quality control inadequacy, and laboratory errors are just a few examples of how human frailty may engender materiel breakdown. *"Other Personnel"* caused accidents constitutes the next lower series. Again human error enters the picture for basically *Homo Sapiens* is the link which breaks in the chain. Mistakes made by mechanics and other technicians, supervisor personnel, tower operators, GCA and CCA operators and landing signal officers are indicative of some of the areas where the blame for an accident may ultimately be placed. The fourth category and smallest numerically includes such causative factors as weather, airport or carrier facilities and bird strikes.

In recapitulation of the first three categories, it becomes obvious that the major problem in accident cause is people. Although man has evolved through a long period of time, there still exists a large void in our knowledge of him. Gradually a body of information has been compiled but there still is a vast ignorance as to man's total performance envelope. The elucidation of this dark area is of utmost importance in the advancement of aviation.

We must address ourselves to this problem now; this is why we must study human error involved in Naval aviation accidents.

We are dedicated to the premise that with time and knowledge the uncertainty associated with predicting human error caused accidents in Naval aviation can be reduced until this uncertainty asymptotically approaches zero as a limit.

3. CONCLUSION

The conclusion to this paper is a motion picture of approximately five minutes duration. It depicts a series of landing accidents aboard several different classes of aircraft carriers involving various aircraft types. The purpose is to give those who are not familiar with Naval aviation some insight into one of the more hazardous areas of operation and an appreciation for the intolerable price paid as a result of human error.

THE ANALYSIS OF HUMAN PERFORMANCE WITHIN THE OPERATIONAL FLIGHT ENVIRONMENT

by

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SUMMARY

The laboratory detection and evaluation by psychophysical measurements of deterioration in a man's ability to pilot a modern aircraft are subject to four important limitations: (a) an arbitrary standard generally must be assumed; (b) available techniques provide data bearing on no more than two dimensions but these data must then be applied to the full six degrees of freedom of the flight environment; (c) the choice of parameters of performance to be measured will strongly influence the conclusions and interpretations; (d) the same data may lead to conflicting interpretations, depending on the statistical procedures employed. This paper will summarize some of the more popular procedures and will attempt to classify them with respect to their dimensional capabilities and the assumptions which define when and how they may be used.

RESUME

La dégradation de l'aptitude humaine à piloter un avion moderne peut être détectée et évaluée à l'aide de mesures psycho-physiques en laboratoire; on se heurte cependant au quatre facteurs limitatifs suivants: (a) il faut généralement se baser sur un critère arbitraire; (b) les données fournies grâce aux techniques actuellement en vigueur portent sur deux dimensions seulement, et doivent cependant être appliquées aux six degrés de liberté intervenant dans les conditions réelles de vol; (c) le choix des paramètres de performance que l'on veut mesurer influence dans une large mesure les conclusions et les interprétations; (d) les mêmes données peuvent donner lieu à des interprétations contradictoires suivant les méthodes statistiques employées. L'auteur exposera succinctement certaines des méthodes les plus fréquemment utilisées et s'efforcera de les classer en fonction de l'étendue de leurs applications et des hypothèses sur lesquelles on se base pour déterminer quand et comment on doit les utiliser.

THE ANALYSIS OF HUMAN PERFORMANCE WITHIN THE OPERATIONAL FLIGHT ENVIRONMENT

Lloyd Hitchcock, Jr, Ph.D.

It has been said that the complexities of measurement increase geometrically as the complexity of the process measured increases arithmetically. Probably nowhere is this better exemplified than in the study of piloting behavior. Fortunately for those working in the area, much can and has been accomplished by the use of qualitative assessment alone. We can label a particular piloting performance as "good" or "bad" without including a quantitative clause stating "*how*-good" or "*how*-bad" the performance actually was. However, the natural desire to make finer distinctions than those that can be based upon qualitative judgments, and the need to formulate probability statements about the potential consequences of piloting behaviors, have led to continued efforts to develop and apply techniques of quantitative measurement in the evaluation of flight performance.

The most commonly used techniques fall into a category, which for lack of a better term, I shall call *referential statistics*. All measures of error fall into this category, with error defined as the deviation of a variable from some arbitrary reference point. The use of such measures obviously requires the specification of a no-error standard. This standard, or reference, may well vary as a function of time, as would be the case in glide path attitude, but the standard must be such that it can be stated a *priori* in quantitative terms. Of course, any inaccuracies in the definition of the error reference will serve to artificially inflate the measured error and thus proportionately reduce the precision and sensitivity of this measurement technique. The deviations from such an error reference may be summarized across time in several ways. A simple comparator circuit may be used to yield a count of the number of times the variable in question exceeds or falls below the reference. If the output of the comparator is integrated, it will provide a statement of the percentage of total measurement time that the variable deviated from the reference level. Quite often the comparators defining when the variable exceeds the reference and when it falls below it are given differential settings. Thus the comparator outputs can be used to define "when" and/or "how long" the flight performance strays outside a specified *tolerance band*. All variations from the absolute reference which fall within the band are disregarded by such a procedure and hence must be assumed to be both equivalently unimportant and benign with respect to their implications for successful aircraft control.

If it is necessary to go beyond statements of "when", "how often", and "how much of the time" a flight parameter deviates from its error referent and discuss the magnitude of the deviations, several techniques are available The deviations of the parameter above and below the reference value can be separately integrated. The integral of the absolute error can be obtained by either summing these two integrals or by inserting a diode-rectifier ahead of a single integrator and disregarding the sign of the deviations

from the outset. If one assumes that the time-constant of the computing equipment used (usually this value is one-second) is equivalent to a unit measure in the digital sense, the concepts of average, or mean, error as well as the temporal variability of the error quantity may be assessed. For this purpose, the standard form for the sums-of-squares of the variance equation $SS = \Sigma X^2 - (\Sigma X)^2/N$ is approximated by the analog computation

$$SS = \left[\int_0^T X^2 - \left(\int_0^T X^2 \right) \Big/ \int_0^T t \right].$$

Here, the number of measurements, N, is approximated by T/t, where T is the duration of the measurement period and t is the unit time-constant of the computing equipment used. Where an error reference may be specified, it may be used as the mean and the variance computed directly by

$$\int_0^T (X - \bar{X})^2 \Big/ \frac{T}{t}.$$

The variance obtained will, of course be expanded by any discrepancy between the error referent and the true arithmetic mean. However, this expansion will not affect comparisons of relative variability and the assumption of a mean value greatly simplifies the scaling problems associated with analog computation. If rapid-sampling digital equipment is available, direct computation of the error variance is possible. The newer forms of signal averaging equipment, though primarily designed as aids in pulling low-level signals from an electronically noisy background, can be used to provide an amplitude histogram which also can be used to derive an estimate of variability.

One value derived from the use of variance estimates can be seen through a comparison of two error tracings which yield the same total integrated error (and hence the same mean error scores) but yield variances of the determined error which differ markedly. Research conducted at the Naval Air Development Center has revealed that the variability of piloting performance is a more sensitive index of the effects of stress and increased pilot work load than is mean error. Another, and perhaps more important, advantage of variance calculations comes from the ability to derive probability statements concerning performance through their use. It is often meaningful to use a statement of upper or lower limits as a referent for performance evaluation. In simulation situations which permit excursions beyond limits to occur with relative safety, the number of limit overshoots may be tabulated directly by counter and/or their duration determined by using temporal integration of a comparator-controlled bias signal. This process is equivalent to expanding the tolerance-band previously discussed all the way out to the structural or performance limits of the aircraft under investigation. However, it is frequently impractical to repeatedly test-to-failure in this fashion. Therefore, prediction must be substituted for tabulation. Such a predictive procedure has been developed for cases in which it would be of interest to determine how long a subject pilot could maintain flight at a given level of performance. This predictive scheme requires both a calculation of response variability and the *a priori* statement of a limit which should not be exceeded by the parameter in question. Using the estimate of standard deviation derived from the variability calculation and the mean response magnitude, the assigned limit is then translated into a z-score by $(L-\bar{X})/s$, where "L" is the limit value, "$\bar{X}$" is the average response magnitude, and "s" is the standard deviation of the response distribution. The

obtained z-score can then be used to enter a table of the normal or Gaussian curve to yield a percentage statement of the probability "p" of observing a response value equal to or greater than the stated limit value. This value is then multiplied by the frequency of sampling rate, $1/t$, in samples-per-second to obtain the probability of observing a limit response in any given second of observation. Such a probability statement yields a rectangular distribution across time. Thus the probability "q" of *not* observing a limit value in x seconds of flight may be derived from

$$q' = \left[1 - \left(\frac{1}{t} P\right)\right]^x$$

Thus $1 - q'$ yields a probability statement regarding the likelihood that a pilot could safely negotiate a prescribed interval of maneuver time at his demonstrated level of proficiency. If only peak values are sampled, the same statement is made possible by using

$$q' = [1 - (\bar{h}_z P)]^x ,$$

where $\bar{h}_z$ is the average response frequency in cycles/second.

Frequently the complexities of the operational environment thwart all our attempts to specify a useful reference against which we may measure performance error. The correctness of a response may be determined by many factors other than a simple correlation between two variables. For example, nosing over slightly to regain a loss of airspeed is a fine general rule, but its application is questionable by a pilot who is positioned just short of a carrier deck. Hence, we find a need for *contingency analysis*. Using comparators to trigger digital components, a series of AND-gates can be constructed which permit a large number of variables to contribute jointly to the definition of error. The utility of this technique is currently being evaluated by application to a study of pilot performance during simulation of severe turbulence penetration. This study, conconducted using the Human Centrifuge of the Naval Air Development Center, simulated the force environment and pilot-controlled aerodynamic responses characteristic of the Boeing 720B aircraft. The procedures currently in use by air carriers using this air aircraft dictate maintenance of horizontal attitude in pitch and role throughout turbulence penetration. However, overzealous adherence to this dictate in the pitch axis is unwise in view of the narrow range of airspeed between stall and high speed buffet characteristic of the 720B at high altitudes and the restrictions upon altitude variation imposed by the air traffic control. Therefore, a nose-high attitude does not always demand a compensating nose-down control input nor does a nose-down attitude always mean a push-forward input is in error. However, if airspeed and rate-of-descent are high, pitch attitude and pitch rate both nose-down, G-load less then one, and altitude is below the prescribed flight level, a nose-down control input can definitely be classified as an error. If the digital logic is programmed to pass an error signal only when these conditions coincide, or when the inverse of these conditions is coupled with a nose-up command, then the circuit output may be used to provide an index of error frequency and/or duration.

The use of such a contingency analysis provides an additional benefit if the data used are upon magnetic tape and permit repetitive analysis. If each component variable in a

contingency sequence is dropped from the circuit in turn, valuable information can be gained about the relative importance placed upon each of the variables by the subject pilots. The influence that a given flight variable has upon the control actions of the pilot will be directly proportional to the increase in error frequency observed when that variable is removed from the contingency sequence. For example, if the circuitry associated with the variables of airspeed and pitch altitude are alternately removed from the contingency analysis of pitch command developed for the turbulence situation, the change in recorded error which occurs when "airspeed" is removed can be compared with the change associated with elimination of the "attitude" variable from the contingency circuit. This comparison will yield a direct ratio index of the relative importance for pitch control placed upon airspeed and attitude by the pilot.

An additional advantage of such a contingency analysis is that it requires the construction of a minimum number of *a priori* assumptions. However, it should be kept in mind that the error index which results is extremely conservative.

Though quantitative analyses such as those described here constitute only primitive first steps toward the goal of precise measurement of piloting performance, it is hoped that experience in their use may lead to extensions which will succeed in penetrating what William James described as the "thicket of reality".

SUSTAINED PILOT PERFORMANCE REQUIRES MORE THAN SKILL

by

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SUMMARY

The USAF School of Aerospace Medicine has conducted a series of studies on management, morale, job satisfaction, and workload among aircrewmen. The impact of such factors on flying efficiency was clearly demonstrated in research during World War II. Modern aircraft and management concepts inherent in the present organization of the USAF have created new problems in these areas. Significant disruptions in the living patterns of aircrewmen have been identified. Significant disruptions of daily patterns of sleeping and eating have been found as a result of flying through several time zones. Management concepts concerning quick response and flexibility in meeting special requirements have been shown to interfere with off-duty recovery from fatiguing missions. These and similar factors reduce the aircrewman's physical and psychological fitness for sustained flying proficiency during demanding missions.

RESUME

L'Ecole de Médecine Aérospatiale de l'Armée de l'Air des Etats-Unis s'est livrée à une série d'études sur l'organisation, le moral, la satisfaction professionnelle, et la charge de travail parmi les membres d'équipages navigants. Les incidences de ces facteurs sur l'efficacité en vol ont été clairement démontrées par des travaux de recherche effectués au cours de la Deuxième Guerre Mondiale. Les avions modernes et les principes qui guident l'organisation actuelle de l'Armée de l'Air des USA ont créé de nouveaux problèmes dans ce domaine. On a identifié des ruptures importantes dans le rythme de vie des navigants, ainsi les perturbations affectant les horiares des repas et du sommeil lors du passage de plusieurs fuseaux horaires. On a démontré, d'autre part, que certains principes d'organisation touchant la rapidité de réaction et la souplesse devant certains impératifs spéciaux contrarient les possibilités de récupération des navigants aprés une mission fatigante. Ces facteurs, ainsi que d'autres du même ordre, réduisent l'aptitude physique et psychologique des navigants à s'acquitter de façon satisfaisante et soutenue des tâches qui leur sont assignées au cours de missions qui requièrent toute leur compétence.

SUSTAINED PILOT PERFORMANCE REQUIRES MORE THEN SKILL

Bryce O.Hartman, Ph.D.
George K.Cantrell, Major, USAF

1. SUSTAINED PILOT PERFORMANCES REQUIRES MORE THAN SKILL

Major nations function globally. Military transport organizations are an important tool in these activities. The aircraft are complex and require the most professional kind of airmanship. Factors other than skill, however, influence the pilot's ability to maintain high levels of performance. The military transport pilot routinely flies to destinations thousands of miles from his home base. Such trips require several days, and produce major changes in the pilot's living and working pattern. It is the purpose of this paper to show the extent to which the daily pattern is disrupted during these long missions.

2. METHOD

Data were obtained in a workload study conducted as part of a special Military Airlift Command crew time test on the C-141. All aircrewmen in two squadrons were given forms on which to report their activities in half-hour blocks around the clock for 20 successive days. Sixty-one aircraft commanders completed all 20 forms without error. Ten of these were in an off-duty status at the beginning of the study, were alerted and went into predeparture crew rest, flew a mission to the Far East, returned, and completed their post-mission crew rest prior to the end of the study. They had therefore gone through the entire cycle involved in an extended mission. These were used in a detailed analysis of daily patterns.

First, a model mission was empirically derived by obtaining modal times for eating, sleeping and flying on each successive day. Intervals between these activities were allotted to functions such as "crew rest", "on the flight line", "clearing operations" and similar aircrew duties arranged in the appropriate sequence. The resulting model was cross-checked against mean times for each activity obtained from the entire 61 aircraft commanders. Then, eating times, sleeping times and flying times reported by the 10 pilots selected for detailed analysis were sorted into two groups, at home or on temporary duty (TDY) away from home, converted to percentages, and plotted on a time scale.

3. RESULTS

The model mission is made up of six flights consisting of a long and medium length leg outbound, and a short and 3 medium length legs inbound. In-transit time is six days, and

the complete cycle, including pre-departure and post-mission crew rest, is eight days, Flight time is 38 hours out of the 144 hours in transit. An analogue of this mission is presented in Figure 1. Figure 2 shows the mission plotted on a day-by-day basis. In-flight and sleep periods, which provide the maximum contrast in activity, are specifically identified. It can be seen that a short 2½ hour flight is the only productive work accomplished during days 3, 4 and 5.

In Figure 3, the times for flights, meals and sleep onset during the six days in transit are plotted on a twenty-four hour scale. The right hand column shows a conventional schedule for comparison. It can be seen that the flights are scattered around the clock and that meal times and sleep lack the pattern characteristic of normal schedules.

The findings presented to this point come from a model. Though empirically derived, it is of course one step away from real data. The following figures summarize the actual times reported by the 10 aircraft commanders for the full 20 days. Frequency distributions were converted to percentages and plotted on a twenty-four hour time scale.

A comparison of take-off times at home and in-transit (TDY) is shown in Figure 4. In-transit take-offs are scattered around the clock. Take-off times at home show a large peak in the afternoon (largely training flights) and a smaller peak in the morning. Furthermore, these aircraft commanders reported no take-offs between 8 p.m. and 4 a.m., a time period during which thirty percent of the in-transit take-offs occurred.

Meal times at home and in transit are compared in Figure 5. In-transit meals show peaks at 2 a.m. and 4 p.m. home base time. An interesting reversal, not immediately apparent in the curve, occurs with the TDY meals: half of them are eaten between the normal supper and breakfast schedule, a shift of twelve hours. The curve for meals at home shows the expected three peaks.

The difference between sleep onset at home and in transit (Fig. 6) is quite striking. Two-thirds of the sleep periods at home begin between 10 p.m. and 2 a.m. Sleep onset times while flying an extended mission are scattered around the clock. However, sleep durations (Fig. 7) are quite similar at home and on TDY.

4. DISCUSSION

It appears that both the model mission and the raw data from the ten aircraft commanders indicate the same thing: a pilot going out on an extended mission enters into an unpatterned schedule of living and working. In the face of this psychological and physiological confusion, the aircrewman can adopt one of three strategies:

(a) He can remain on a home base schedule, but this puts him out of step with the pattern at every stop-over point and is sometimes physically impossible because, for example, he is flying when the home base schedule says he should be sleeping.

(b) He can shift to the local schedule at each stop-over, but this produces conflicts with the previous schedule, so that he may find himself eating or going to bed too soon, or having to defer eating or sleeping despite a physiological need. (Furthermore, this does not alter the lack of patterning. We reprogrammed eating and sleeping on this basis in the model mission and derived a different but equally unpatterned daily schedule.)

(c) He can anchor his schedule to the airplane's flying schedule, a compromise which our data say he has, in fact, adopted even in the face of the consequent disruption.

Clearly none of the strategies solve the problem.

What are the consequences of this disruption? We must report that we don't know. We have been trying for several years to find changes in psychomotor efficiency when the living and working pattern is altered. We have carried out simulator and field studies on aircrews, simulated space flights, work/rest experiments, and fatigue studies. Hauty's recent demonstration of decrement in simple tasks[1] supports our concern about the importance of the problem. It is well known that changes in the pattern alter cyclical physiological functions. These alterations have been detected in many studies, but the effect in the psychomotor domain - a loss in piloting skill - remains elusive. We know from our field studies of aircrewmen that they are largely dissatisfied with their lot when flying extended missions and are more satisfied back home. We think that the appropriate laboratory experiments and field studies remain to be performed.

Finally, we are sure that the training programs do not prepare pilots for this kind of disruption of normal patterns of living and working, and that the highest order of piloting skill is of little assistance in coping with it.

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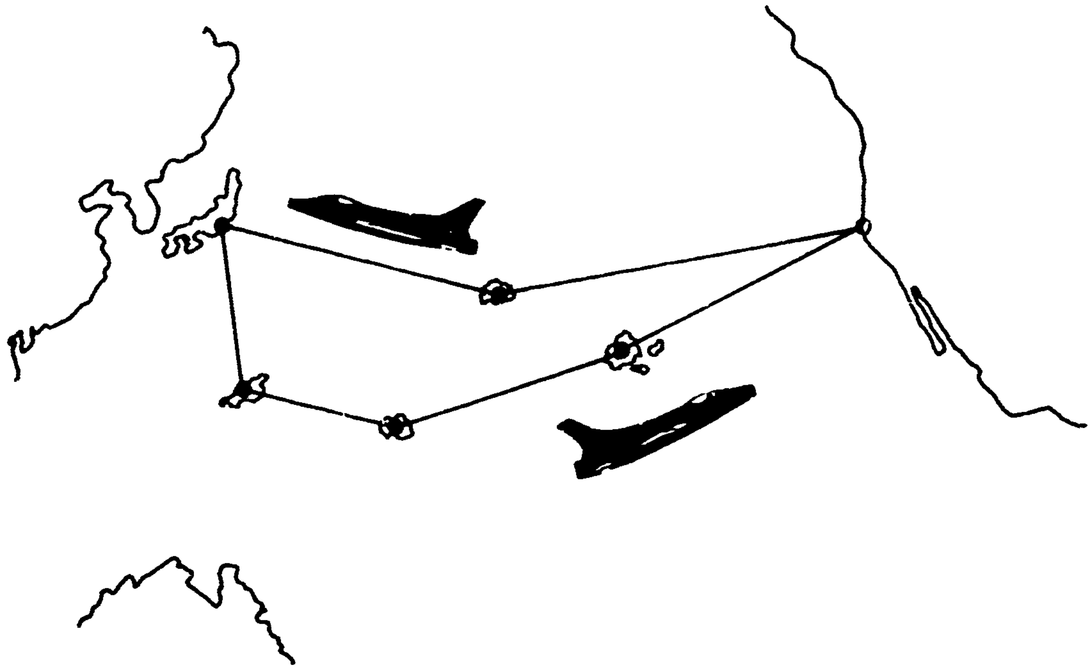

Fig. 1 An analogue of the model mission, fitted to routes from the west coast of the United States to Japan and back.

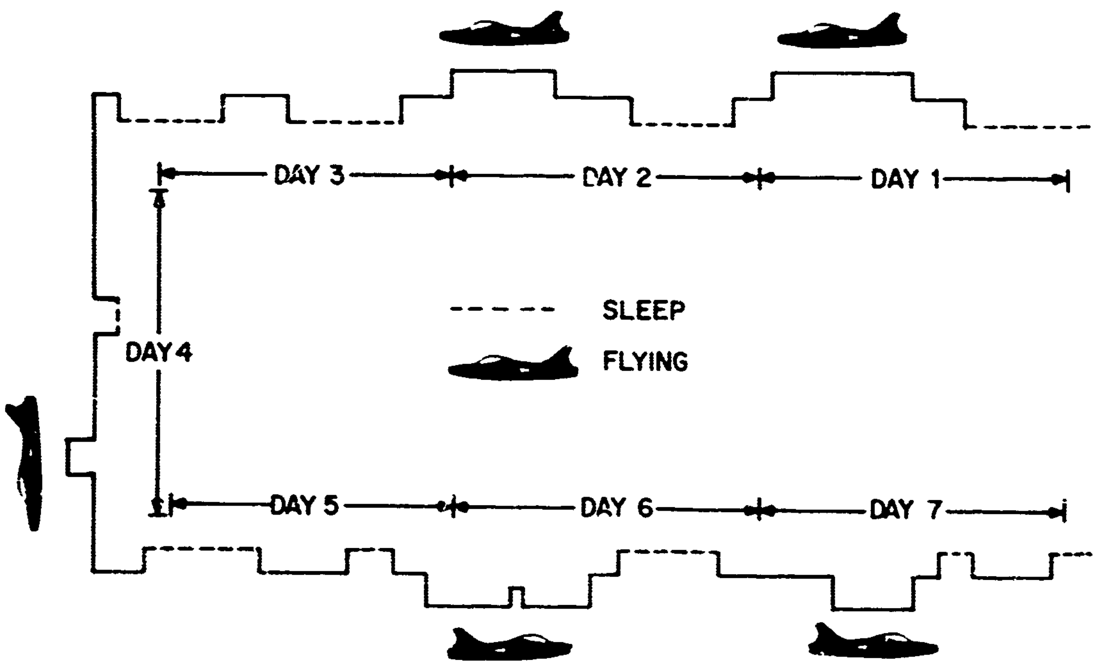

Fig. 2 A day by day plot of the model mission, using flying and sleeping to provide maximum contrast in activity.

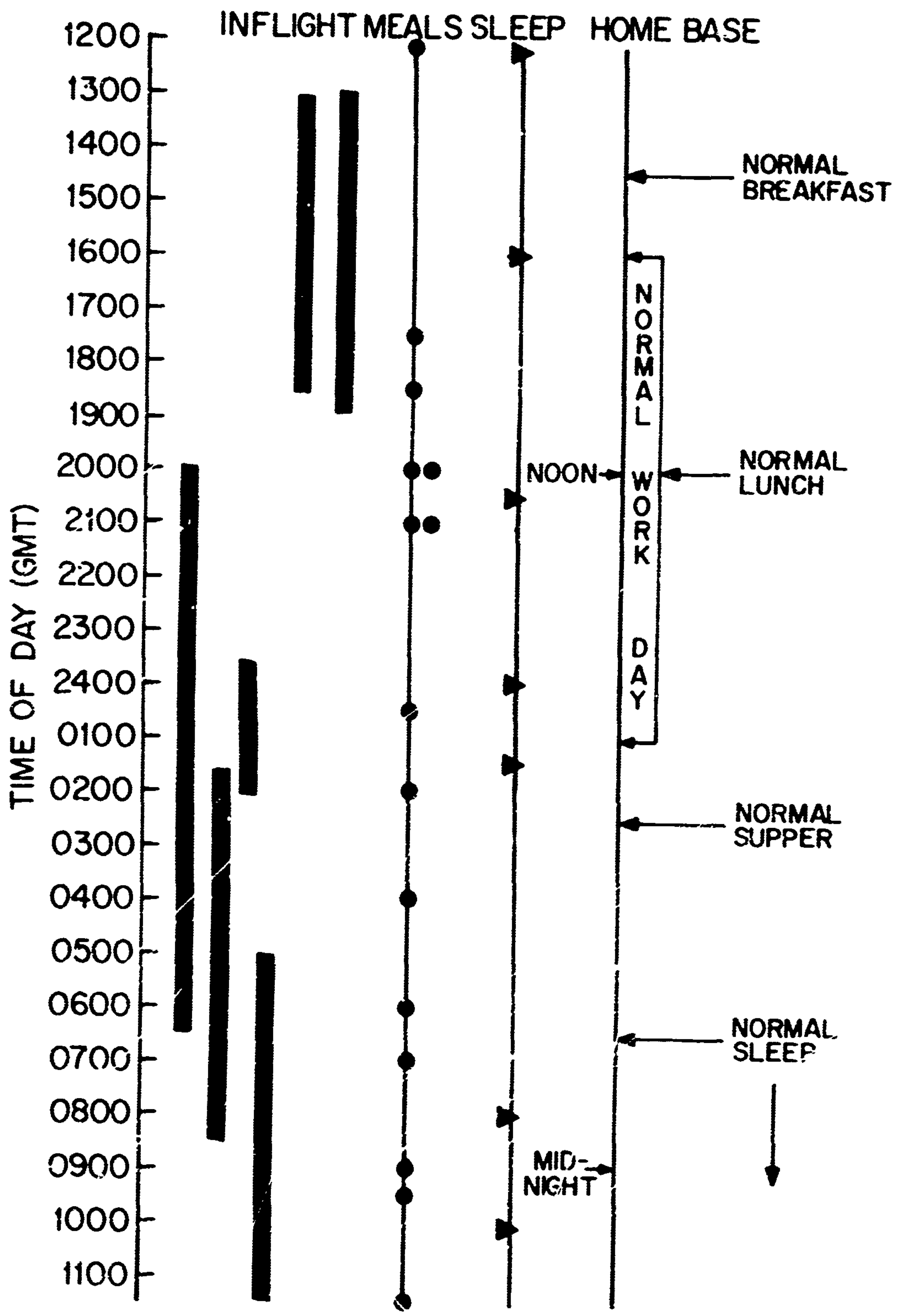

Fig. 3 In-transit activities during six days collapsed into a single day. The right hand column shows a conventional daily pattern.

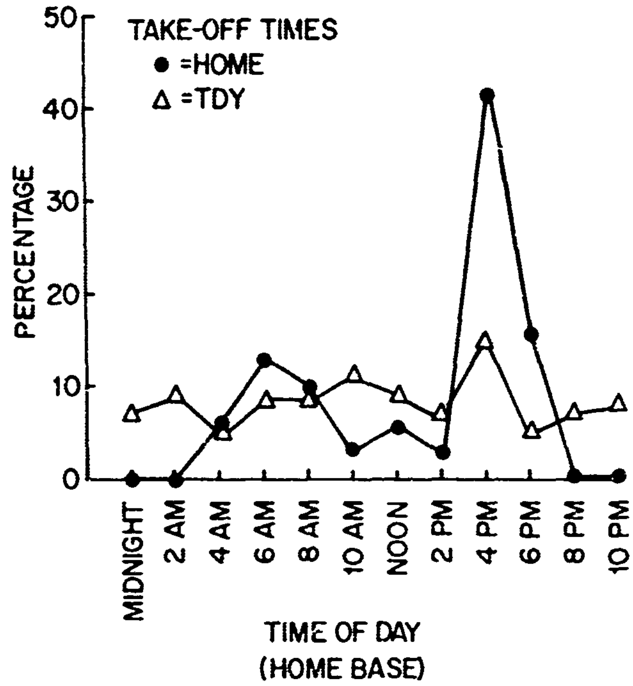

Fig. 4 Comparison of take-off times at home and on an extended mission.

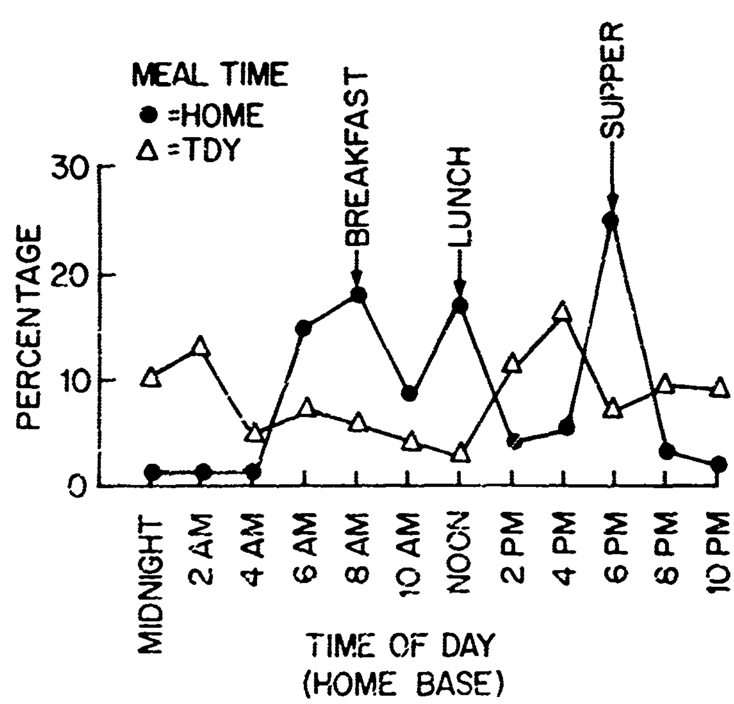

Fig. 5 Comparison of meal times at home and on an extended mission.

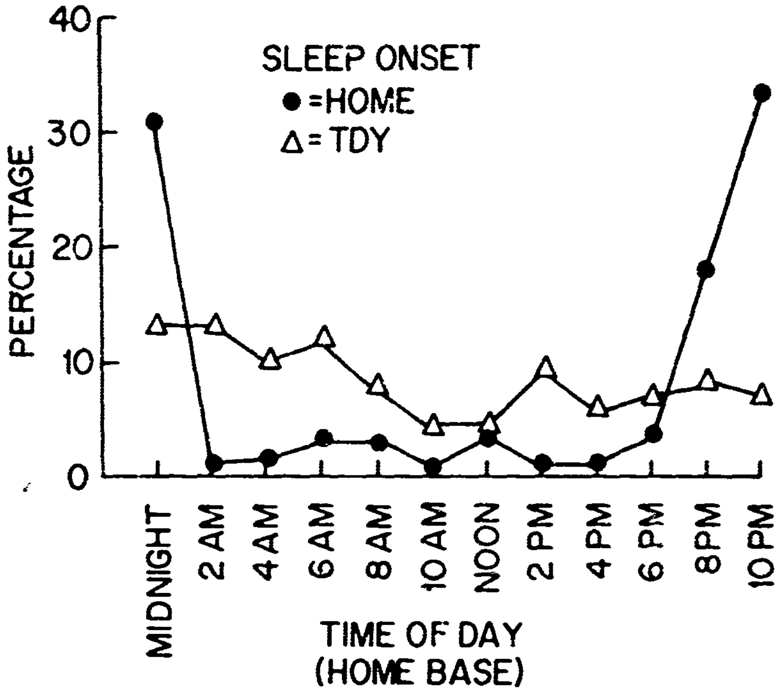

Fig. 6 Comparison of sleep onset times at home and on an extended mission.

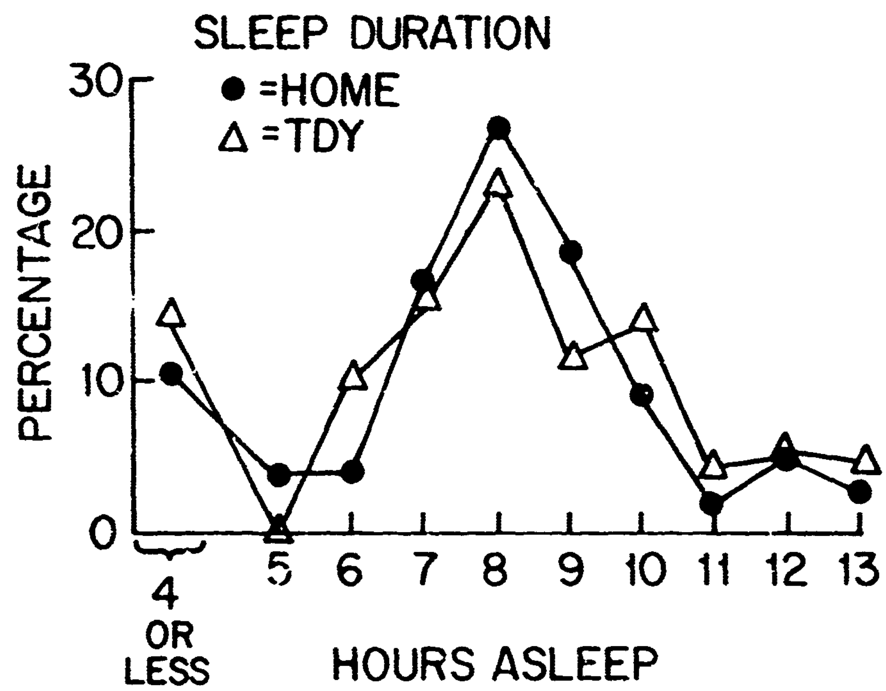

Fig. 7 Comparison of sleep durations at home and on an extended mission.

SLEEP RHYTHMS IN TRANSATLANTIC CIVIL FLYING

by

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SUMMARY

A number of east-west and west-east flights have been carried out in civil aircraft (Boeing 707 and Super VC10). These flights have been to New York, Bermuda, Singapore and Boston - Detroit. The parameters recorded and made use of in the present investigation were pulse rate from take off to landing, with some short breaks in recording when the Captain who was being investigated, had to go aft for natural or for social purposes. A log was kept of activities on the flight deck and of the periods of sleep during the slip period.

The amount of sleep taken seems to be reflected in the changes in heart rate recorded at various periods of the flight. If the Captain has to fly during a period in which he would normally be sleeping, then, obviously, he must either have a sound and full night's sleep to whatever is the number of hours he usually requires, or he must in addition "bank" some sleep by sleeping in the middle of the day. To do this "banking" in an environment which is not conducive to sleep, introduces difficulties. For these reasons, it seems that a Captain is more liable to be fatigued by westerly flight in which the take-of time is in early evening as opposed to one in which the take-off time is in the late morning.

An attempt has been made to relate the degree of tiredness resultant from this sleep loss together with the fatigue produced by the flying task itself, to the pattern of cardiac activity during flight period.

A fatigue check list modified from one designed by the United States Air Force has also been employed in this investigation.

RESUME

Un certain nombre de vols ouest-est et retour ont été effectués à bord d'avions civils (Boeing 707 et Super VC10), avec, pour objectifs, New York, les Bermudes, Singapour, et Detroit par Boston. Le paramètre enregistré et utilisé au cours de l'étude réalisée à cette occasion était la fréquence du pouls depuis le Décollage jusqu'à l'atterrissage, à l'exception de quelques interruptions d'enregistrement dues aux déplacements, vers l'arrière de l'appareil, pour des obligations sociales aussi bien que des besoins naturels, du commandant soumis à l'expérience. Les activités à l'intérieur de la cabine de pilotage et les phases de sommeil au cours de la période de repos entre deux relèves d'équipage, furent consignées dans le journal de bord.

Les variations de la fréquence cardiaque enregistrée à divers moments du vol semblent être fonction du nombre d'heures pendant lesquelles le sujet a pu dormir. Si le commandant doit voler au cours d'une période normalement consacrée au sommeil, il lui faut, de toute évidence, soit avoir une bonne nuit de sommeil profond, de la durée à laquelle il est habitué, soit "stocker" en plus une certaine quantité de sommeil en dormant en milieu de journée. Cependant, ce "stockage", effectué dans des conditions ambiantes impropres au sommeil, soulève des difficultés. Il semble donc qu'un commandant, est plus vulnérable à la fatigue au cours d'un vol en direction de l'ouest, avec décollage en début de soirée, qu'au cours d'un vol avec décollage en fin de matinée.

On s'est efforcé d'établir le rapport entre le degré de fatigue résultant d'une part de ce manque de sommeil, d'autre part des fonctions de pilotage proprement dites, et la courbe de l'activité cardiaque pendant le vol.

SLEEP RHYTHMS IN TRANSATLANTIC CIVIL FLYING

Wing Commander T.C.D. Whiteside

A number of east-to-west and west-to-east flights have been carried out in civil aircraft (Boeing 707 and Super VC10) leaving from London. During these flights heart rate was almost continually recorded on magnetic tape from take off to touch down. Seated behind the captain on each flight was a scientific observer who kept a log of salient features of the flight noting, for example, changes in altitude or in heading, discussions on R/T regarding clearance to a certain flight level, etc. In this way it was possible subsequently to correlate in time, the heart rate with the various events recorded. Furthermore, all urine passed from 12 hours before leaving home, until 12 hours after returning, was collected and acidified for subsequent examination to determine the amount of adrenaline and noradrenaline excreted. Subjective fatigue was quantified by means of a modified version of a questionnaire developed by the USAF. The results indicate that probably the most important single factor contributing to fatigue in this task is the loss of sleep which inevitably arises from a number of causes, mostly associated with the phase difference between the sleep rhythm to which the individual is adapted and the sleeping time of the local community in which he finds himself. In general this phase difference, in degrees, is equal to the number of degress difference between the longitude to which the individual is adapted and that in which he finds himself. If he is west of the longitude to which he is adapted the environment is in phase lag, whereas if he is east of the longitude to which he is adapted the environment is in phase advance.

The problems associated with sleep when west of the usual time zone are not in general in getting to sleep, since if one is following the habits of the local community this means going to bed later than usual. The difficulty is rather in remaining asleep until the local community wakens, for there is a tendency to find oneself waking at about 2 or 3 o'clock in the morning and being unable thereafter to get to sleep again. This is attributed to the normal circadian rhythm and the associated activity in the reticular formation giving rise to arousal ascendant impulses. It seems probable that this mechanism which has been suggested by Bremer (1954) may well be the stimulus which causes the individual to waken at those early hours - a time in fact which corresponds precisely with the usual time at which the individual wakens when he is at home. It is, for example, well known that, even after going to bed very late, one none the less tends to waken about the same time as usual in the morning. The net result is that when sleeping west of the time zone to which one is adapted, sleep tends to be curtailed, firstly by getting to bed late, and secondly, by waking too early.

When east of the time zone to which one is adapted, the time of going to sleep tends to be, by local standards, later, for that environment is in phase advance. If one tries to go to bed at the local time for doing so, this may in fact mean retiring some five to seven hours too early and of course it can then be difficult to get to sleep. This can

of course be somewhat easier if the individual has previously incurred a sleep debt or if he is tired from having been on duty. The time of waking is dictated rather by the noise of the wakening community and since this occurs before one's usual waking time, the night's sleep is shortened. To summarise; when there is displacement east or west of the usual time zone there is usually inevitably a reduction in the amount of sleep obtained.

When west of the customary time zone the difficulty in getting to sleep is of exogenous origin and the difficulty in rmaining asleep in the early morning is of endogenous origin. When east of the customary time zone, the difficulty in getting to sleep is of endogenous origin, and the difficulty in remaining asleep is of exogenous origin.

To meet these difficulties the captains who had volunteered to be subjects of the investigation had each evolved a system of sleep pattern when en route. This involved taking the post-flight sleep, but only after allowing a run-down period of at least some three to five hours. This allowed the individual to relax after the demanding task of flying and, in the case of westerly flights, it enabled him to fall into phase with the local sleeping habits. When the period of slip was of the order of 24 - 36 hours, the reduction in the sleep obtained in this post-flight period was made use of to enable the individual to get to sleep again for three to four hours so as to waken as near as convenient to the next take-off time.

Even under those circumstances however, on occasion, some schedules were associated with an individual flying whilst in sleep debt. When such sleep debts were examined in relation to a subjective score for the degree of tiredness felt by the individual, it was found that on many occasions there was considerable agreement between the two. The most tiring conditions of all occurred when an individual, in addition to having a sleep debt, also had to fly during the hours that his circadian rhythm would normally associate with sleep.

NAVIGATION OF HELICOPTERS IN SLOW AND VERY LOW FLIGHT

A COMPARISON OF SOLO AND DUAL PILOT PERFORMANCE

by

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SUMMARY

This study, using CH112 light helicopters and experienced pilots, was aimed toward answering two questions: Can the Army helicopter pilot navigate and simultaneously fly very low when, without the opportunity for briefing, he must fly between successive points in unfamiliar, relatively featureless terrain? Is there a difference in navigation accuracy when the task is shared by two pilots forming a pilot and navigator team?

Six pilots participated in a comparison of solo and dual performance, in which 358 short tracks were flown in the course of thirty-six sorties. Each track could be described as a short flight in itself, since each was terminated by a landing. In the dual sorties, the task was shared by two pilots - one responsible for flying the helicopter, the other concerned solely with navigation.

No difference was found between dual and solo performance in terms of the numbers of endpoints reached (entering a circle of one-eighth mile radius at the endpoints). Advantages of a secondary nature, however, were shown for the dual teams, e.g., smaller errors in landings beyond the criterion circle, fewer intial heading errors and enroute "sit downs".

At the conclusion of the main trial a small test was conducted in which dual teams were permitted to fly routes of their choice as opposed to straight tracks. Although no statistical validity can be attached to the meagre post-trial data, it appears that improved performance is possible, but the duration of sorties may be greatly increased.

RESUME

Le but de cette étude, menée sur hélicoptères légers CH112 avec l'assistance de pilotes expérimentés, était de répondre à deux questions: un pilote d'hélicoptère de l'Armée de Terre peut-il s'acquitter des fonctions de navigateur tout en volant à de trés faibles altitudes lorsque, sans avoir pu recevoir d'instructions, il doit relier deux points successifs au-dessus d'une zone qui lui est inconnue et qui ne comporte pas de repères marquants? Ces fonctions de navigateur sont-elles remplies avec une précision supérieure lorsqu'elles sont partagées par deux pilotes formant une équipe navigateur-pilote?

Six pilotes ont participé à une étude comparative des performances en vol solo et vol à deux, étude consistant en 36 sorties au cours desquelles furent parcourus 358 courts itinéraires. Ces itinéraires peuvent être considérés comme autant de vols proprement dits, car, s'ils furent de courte durée, tous se terminèrent néanmoins par un atterrissage. Dans les sorties en équipe, les deux pilotes se partagèrent les tâches, l'un étant responsable du pilotage de l'hélicoptère, l'autre de la navigation seulement.

On ne constata pas de différence entre les performances en vol solo et vol à deux, du point de vue des destinations atteintes (il s'agissait de pénétrer à l'intérieur d'un cercle d'un rayon d'1/8ème de mille, rayon dont les destinations finales constituaient les extrêmités. Par contre, les vols en équipe de deux présentèrent certains avantages de nature secondaire, tels que écarts d'atterrissage plus faibles par rapport au cercle choisi comme critère, moins d'erreurs de cap initiales et d'arrêts en cours de vol.

Une fois cette série d'expériences terminée, il fut procédé à un essai de moindre ampleur au cours duquel on permit à des équipes de deux de suivre des trajectoires de vol de leur choix au lieu des itinéraires directs. Bien que l'on ne puisse attacher de valeur statistique aux quelques données obtenues grâce à cette expérience, il semble qu'une amélioration des performances soit possible et que la durée des sorties puisse être nettement prolongée.

NAVIGATION OF HELICOPTERS IN SLOW AND VERY LOW FLIGHT*
A COMPARISON OF SOLO AND DUAL PILOT PERFORMANCE

Ronald E.F.Lewis

In recent years it has been our privilege at DRML to work in close collaboration with Canadian Army aviators whilst studying the problems confronting the pilot who must fly slow, very low and, at the same time, navigate with considerable precision.

We have designed field trials which present pilots with operationally realistic conditions and yield reliable performance data. We choose to work in the field trial medium because the Army aviator flies in a way uniquely hazardous and no simulator can reproduce these conditions. The lower the Army aviator flies, the safer, generally speaking, he is in relation to ground fire and yet the more likely to hit wires or trees. A curious combination of circumstances in which to operate!

This is the third of a series of studies on the performance of Army pilots navigating at low level. Two questions were asked:

(i) Can a dual pilot team navigate more accurately than a *solo* pilot?

(ii) What is the effect of eliminating pre-flight briefing?

The latter question arises because, once airborne, a helicopter may be ordered to go to points other than those determined before the flight. These questions were the substance of a field trial undertaken by the Human Engineering Group of DRML using CH112 Hiller helicopters and experienced helicopter pilots.

The trial design called for six pilots to fly 360 short tracks (between three-quarters and three and a quarter miles in length) in the course of thirty-six flights. Each track was a short flight in itself since each terminated in a landing.

Terrain for this trial was a shallow hill range in the Province of Manitoba. The many similar hills made for difficult terrain in which to navigate at very low level and there also was a dearth of easily recognizable topographic features. None of the pilots had flown low in the area previously.

The subject pilots flew dual and solo flights but never over repeated tracks. In the dual flights, one pilot navigated and gave verbal intercom instructions to the pilot flying the helicopter. In solo flights the pilot performed both tasks simultaneously.

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* A more detailed account is given in DRML Report No.609.

Helicopter speed was between 40 and 60 knots. Most tracks were flown at 50 knots. Instructions to pilots were summarized in this way:

(1) Reach the endpoints.

(2) Stay on track.

(3) Fly as low as possible with safety.

A typical sortie was flown in the following way. After landing at an area entry point, the pilot was handed a map section on which was drawn the first track to be flown. The pilot estimated the course to be flown and flew the track, landing at which he judged to be the endpoint. The investigator (who accompanied the pilots on all flights) then substituted a second map sheet for the first. This new sheet showed the track just attempted and the track to be flown next. This procedure was follwed until ten tracks had been completed.

The problem of handling a map sheet in a helicopter which requires both hands on the controls was solved by installing a simple map holder. The holder could be rotated through 360° and the track drawn on the map oriented with aircraft heading.

Navigation performance was recorded in a simple but accurate way. A chase helicopter accompanied the low flying test helicopter and carried an experienced navigator/pilot whose sole task was to plot the track of the test helicopter. This can be done quite accurately from 300 feet since contours and adjacent features combine to give good cross-bearing information.

When the results of this trial were computed, we were surprised to find negligible differences between dual and solo performance in terms of the number of endpoints reached. The criterion in this trial was entry into a one-eighth mile radius circle drawn about the endpoints. Overall performance had dropped from the levels achieved in the earlier fixed-wing trials to 60%. Ability to reach the endpoint is, of course, the only true test of navigation performance.

As stated earlier, the pilot landed at what he considered to be the endpoint. Occasionally he was rudely awakened to the fact that he was far from where he thought he was. One very experienced pilot felt confident enough to spontaneously describe the way in which features on the ground married with those on the map. This went on through seven consecutive tracks until a highway appeared which was not on the map!

Examination of the data revealed secondary ways in which dual and solo performance differed, showing to advantage the effect of a dual team.

(a) Distribution of the endpoint landings outside of the quarter-mile endpoint circles showed a much looser grouping for the solo attempts. This occured perhaps because the solo pilot did not find time to carefully check the features about the endpoints in relation to his 1/50,000 sheet.

(b) Sit-downs, as opportunities to pause and think, were resorted to on more occasions by the solo pilots than the dual teams; somewhat dangerous pauses, in an operational situation. Clearly, a sitting helicopter is more vulnerable to concealed fire power than a helicopter in flight.

(c) Heading error at the beginning of a leg is another score which showed the dual team advantage. Although both groups made initial heading errors, significantly fewer errors were made by the dual group. These errors were scored only if they persisted for more than half a mile. Initial heading is, of course, a function of the helicopter position at the start of a leg. If the *previous* track was flown correctly and followed by a correct estimate of the course to steer to make good the *next* leg, then the pilot would see features coming up which would marry with those on the map. If, on the other hand, he finished the previous track incorrectly, but *thought he was in the right spot,* his assessment of the new course to steer would be inappropriate, and would probably be changed because the feature coming up would not *marry* with the map. His dilemma was the, "which side of track am I?" It may not have been resolved until a clearly identifiable feature appeared. It is therefore not surprising that the advantage to be gained from the correct point was clearly demonstrated for both groups.

Curiously, the length of the track had no effect on performance. This was probably because of the relatively short track lengths and the lack of features en route.

High tension and telephone wires were again a constant threat and trees also were a problem to the extent that we clipped one tree and were very nearly in collision with wires on six occasions.

We conclude that straight-line navigation in these conditions asks too much of both dual and solo pilots. A 60% success level for experienced pilots implies a lower score for less experienced pilots. There is now a strong case for providing an automatic navigation aid in the helicopter if straight line navigation between points is desirable. But if the job must be done by the aircrew, the pilot/navigator team is superior when several factors are considered. However, in terms of endpoint score, one pilot can navigate and fly as effectively as the dual team and *reach* the endpoints under these very difficult conditions.

As the trial proceeded, informal conversation with the pilots revealed their considerable enthusiasm for navigating from A to B along tracks of their choice rather than by the direct method used throughout the trial. Accordingly, as a post-trial exercise, the dual teams were each asked to fly two similar sorties in which, before each leg was flown, the dual team mutually agreed upon and drew the track that they would follow. In all other respects the four flights were flown under the start conditions of the main trial. It must be emphasized that data obtained from the small post-trial exercise should not be considered reliable in statistical terms.

By flying their own routes they were 72% successful in reaching the quarter-mile endpoint circles. When they failed to reach the quarter-mile circle it was a miss by a comparatively short distance. But against this indication of success must be offset the considerable distance which the crews *did in fact fly* as opposed to their intended routes and the straight line route. Also, there may well be tactical hazards associated with the practice of deliberately flying to main features and along them in the case of wires, railroads, tree-lines and roads, etc.

Finally, it is interesting to see the tracks for all flights superimposed. Accurate en route navigation would have resulted in a thin line - an overlay of intended and actual tracks. An automatic navigation system should result in much improved en route

navigation but within the "state-of-the-art" will likely be no more accurate than plus or minus 1% of distance flown from the last accurate updating. We will be left with an ugly question. What must the aviator do when his black box display says "you are there" and he isn't!

DEVELOPMENT OF THE

SPATIAL ORIENTATION TRAINER

by

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SUMMARY

Spatial disorientation is a primary compromiser of pilot performance. The problem confronting the flight surgeon in his attempts to eliminate spatial disorientation accidents has been threefold. First, he would like to be able to demonstrate effectively to pilots that spatial disorientation can happen to anyone. Second, he would like to be able to discern, through testing, which pilots might be prone to lose aircraft control under disorienting conditions. Third, he would like to be able to offer pilots a means by which they can become resistant to the effects of disorienting influences.

The USAF School of Aerospace Medicine is currently developing ordnance for the flight surgeon's attack on the problem of spatial disorientation. The Spatial Disorientation Demonstrator was developed to show pilots that, under IFR conditions, they can be disoriented at will by certain angular and linear accelerations. The principle of the Spatial Disorientation Demonstrator was then incorporated in the design of a new device, the Spatial Disorientation Trainer. This device is intended to serve not only the demonstration function, but also the functions of testing and training: it is designed to differentiate between disorientation-accident-prone pilots and disorientation-accident-resistant ones as well as to give pilots a chance to develop, through artificial practice, resistance to the effects of disorienting influences. The Spatial Orientation Trainer will also be used as a research tool for studying, under relatively realistic conditions, some of the factors that contribute to disorientation accidents.

The physiological principles that underlie the success of the Spatial Disorientation Demonstrator are explained. The Spatial Orientation Trainer is analysed in terms of its mechanisms of action, its capabilities, and its potential application to Air Force needs.

RESUME

La désorientation spatiale est l'un des principaux facteurs qui compromettent la capacité fonctionnelle du pilote. Dans sa lutte contre les accidents dûs à la désorientation spatiale, le "flight surgeon" doit faire face à trois sortes de problèmes. Tout d'abord, démontrer clairement aux pilotes que nul d'entre eux n'est à l'abri de la désorientation spatiale. Ensuite, détecter, à l'aide de tests, les sujets enclins à perdre le contrôle de leur avion sous l'emprise de la désorientation. Troisièmement, donner aux pilotes le moyen de résister aux effets des facteurs de désorientation.

L'Ecole de Médecine Aérospatiale de l'Armée de l'Air des Etats-Unis met actuellement au point les moyens propres à permettre aux "flight surgeons" de s'attaquer à ce problème. Le dispositif de Démonstration de Désorientation Spatiale a été mis au point pour démontrer aux pilotes que, dans les conditions de vol aux instruments, on peut les désorienter a volonté à l'aide de certaines accélérations angulaires et linéaires. On a ensuite intégré le principe du Démonstrateur de Désorientation Spatiale à un nouveau dispositif appelé Simulateur d'Entraînement à l'Orientation Spatiale, destiné à remplir plusieurs fonctions, non seulement celle de démonstration, mais aussi celle d'expérimentation et d'entraînement. Ce dispositif a été conçu dans le but de différencier, parmi les pilotes, les sujets résistants aux accidents de la désorientation, des sujets vulnérables, et, en outre, de permettre à ces derniers d'apprendre à surmonter, grâce à des procédés artificiels, les effets de la désorientation. Le Simpulateur d'Entraînement à l'Orientation Spatiale servira égelement d'instrument de recherche pour étudier, dans les conditions relativement réalistes, certains des facteurs qui entrent en jeu dans les accidents dûs à la désorientation.

L'auteur expose les principes physiologiques sur lesquels repose le succés du Démonstrateur de Désorientation Spatiale. Il analyse enfin le Simulateur d'Entraînement à l'Orientation Spatiale sous l'angle de son mécanisme d'action, de ses possibilités, et de ses applications éventuelles aux besoins de l'Armée de l'Air.

DEVELOPMENT OF THE SPATIAL ORIENTATION TRAINER

Kent K. Gillingham, Captain, USAF, MC

Spatial disorientation has been a deadly compromiser of pilot performance ever since blind flying was first attempted. Slowly over the past several decades basic knowledge of the pathogenesis of spatial disorientation has been accumulated, and we are ready to apply some of that knowledge to the task of decreasing spatial disorientation accidents through the use of a special training vehicle.

The United States Air Force officially recognized the necessity for such a vehicle by establishing a threefold requirement outlining the desired functions of a proposed spatial disorientation training device. The device to be developed and procured would

(i) demonstrate to pilots that sensory illusions of orientation can and will occur in all pilots,

(ii) evaluate pilots for susceptibility to performance decrements caused by disorientation.

(iii) train pilots to become more proficient at coping with disorientation.

The first device to be fabricated in response to this requirement was the Spatial Disorientation Demonstrator[1] (Fig. 1). The SDD is, in effect, a very inexpensive short-arm centrifuge, the cabin of which travels along a circular (10 ft diameter) track at angular velocities up to 25 r.p.m. The cabin can be rotated continuously about its vertical axis and positioned to face any direction relative to the hub of the apparatus. The vertical axis of the cabin itself can be titled ±15° about a tangential axis, so as to allow the cabin to pitch or roll, depending upon the direction in which the cabin is facing (Fig. 2). The inside of the cabin resembles an F-100 cockpit and contains a functioning attitude indicator. The pilot, riding in the cabin of the SDD, can be subjected not only to constant angular velocities up to 25 r.p.m. in the main yaw plane with concomitant linear (centripetal) accelerations up to 1g, but also to various other angular velocities and angular accelerations in the pitch, roll, and planetary yaw planes. By proper manipulation of the controls, the operator can cause the pilot to experience a number of vestibular illusions that occur in flight and lead to spatial disorientation. Two vestibular illusions which are extremely important from the standpoint of flight safety are the Coriolis[2] and oculogravic[3] illusions; the mechanisms of development of these illusions and their roles in the causation of spatial disorientation accidents are among the best understood at the present time, just as the results of these particular illusions are among the most fatal.

The Coriolis illusion (Fig. 3) results during protracted angular velocities when the head is rotated in a plane that cuts across the plane of the continuing angular velocity. The illusion suffered following the coupling of such angular motions is one of undergoing

rotation in a plane in which no actual rotation has occurred. If one yaws at a reasonably constant velocity for about ten seconds, for example, and then pitches his head forward while the yaw is persisting, he will experience a sensation of roll; similarly, if he is pitching and then rolls, he will experience the false sensation of yaw. The Coriolis illusion has been blamed, and reasonably so, for a number of aircraft accidents that have occurred during penetration turns, when radio frequency changes and other cockput duties require extreme head movements. When the SDD is operated at a high angular velocity around the track, and pitching or rolling motions of the cabin are superimposed, a pilot riding the device experiences very distinct Coriolis illusions. Under those conditions, illusions of roll and pitch, respectively, are generated; and the inaccuracy of the pilot's perceptions are demonstrated to him by the attitude indicator.

The oculogravic illusion occurs when the inertial force of a large linear acceleration combines with the force of gravity to form a resultant force which is falsely construed by the pilot to be acting in the same direction as the force of gravity (Fig. 4).* This illusion is common during night and weather take-offs in high performance aircraft, and the all too-frequent results of the illusion are full-power crashes several miles from the end of the runway. The SDD, by means of centrifugal force, can produce the oculogravic illusion when it is revolving with the nose of the cabin facing the hub of the apparatus. The pilot riding the device appreciates his illusion of nose-high attitude when he compares his sensation with the display of his true attitude on the gyro horizon.

Several other classic illusions of flight can be generated in the SDD, but the Coriolis and oculogravic illusions are very spectacular yet reproducible illusions and are thus best suited for demonstration in the SDD.

Although the SDD proved that some important illusions of flight can be reproduced and effectively demonstrated by a relatively inexpensive and safe ground-based apparatus, it was nevertheless not designed to satisfy the evaluation and training functions desired of the ultimate vehicle requested by the Air Force. Utilizing the successful concepts involved in the SDD, and incorporating several additional capabilities, the Spatial Orientation Trainer (SOT) was designed to satisfy the aforementioned requirement (Fig. 5). The most important new feature of the SOT is that the pilot can control its attitude with a control stick. By moving the stick laterally he can roll the vehicle through 180°, and by fore-and-aft-stick movement he can accomplish up to 60° of pitching motion. The pilot can pitch and roll the machine at rates which approach the pitch and roll rates of modern aircraft, and can accomplish both motions simultaneously. The greater angular velocities and displacements for which the SOT is designed give it the capability to generate sensory illusions of much greater magnitude. More importantly, however, it is anticipated that with the incorporation of the functional control stick in the SOT, a much more versatile vehicle than the SDD will be realized, for the following reasons.

If the pilot has control over the attitude of the vehicle, he can be asked to perform a particular maneuver by reference to the attitude gyro. His performance of the requested task can then be monitored and compared with the performance of other pilots or with his own previous performance. If a pilot is instructed, for example, to fly

* The oculogravic illusion, in its original sense, referred only to the displacement of objects in the visual field concomitant with the application to the body of the resultant force described above. Because of the lack of an existing term covering the total sensation associated with such a resultant force, we are expanding the meaning of oculogravic illusion to include not only the visual aspects but also the illusory sensations of attitude and motion generated by the combination of inertial forces with the force of gravity.

straight and level after having been subjected to a Coriolis illusion, and he is unable to accomplish straight and level flight in the vehicle by a certain elapsed time, we might then be able to conclude that his flying performance, is more vulnerable to spatial disorientation than that of another pilot who obtains straight and level flight in less elapsed time. Thus, we believe, an evaluation can be made of a pilot's ability to perform under the stress of conditions conducive to spatial disorientation.

If some pilots, as a result of having been tested on the SOT, appear to be relatively susceptible to performance decrement during disorienting situations, then the SOT will, we anticipate, be useful in training those pilots to resist the influences of disorientation. If susceptible pilots practice controlling the attitude of the vehicle while they are disoriented, then after several hours of such practice they should become less susceptible. We assume that the pilot who has resisted the effects of disorientation in the SOT will be able, should the need arise, to perform more adequately in the air than he would, had he not had such practice. The reasoning behind this assumption is that safe recovery from disorientation in flight involves the pilot's being able to make aircraft control movements solely in response to the visual information provided by the attitude gyro and other instruments, to the exclusion of vestibular and proprioceptive stimuli that are erroneous; such ability takes practice. Thus we anticipate that the SOT will function as a trainer as well as an evaluator and demonstrator, as required by the Air Force.

At present we can only suggest the ways in which the SOT will be put to its optimum use. We believe that undergraduate pilots should receive several hours of training in the SOT: first, to show them that spatial disorientation can occur, and second, to give them practice in overriding illusory orientation cues and successfully controlling aircraft attitude by reference to flight instruments. We believe also that the SOT can be used by the flight surgeon to obtain a meaningful measurement of a pilot's susceptibility to disorientation. We furthermore believe that the SOT will be helpful in providing needful pilots a means by which they can maintain some degree of practice and proficiency in that type of instrument discipline which spells the difference between life and death during critical episodes of spatial disorientation.

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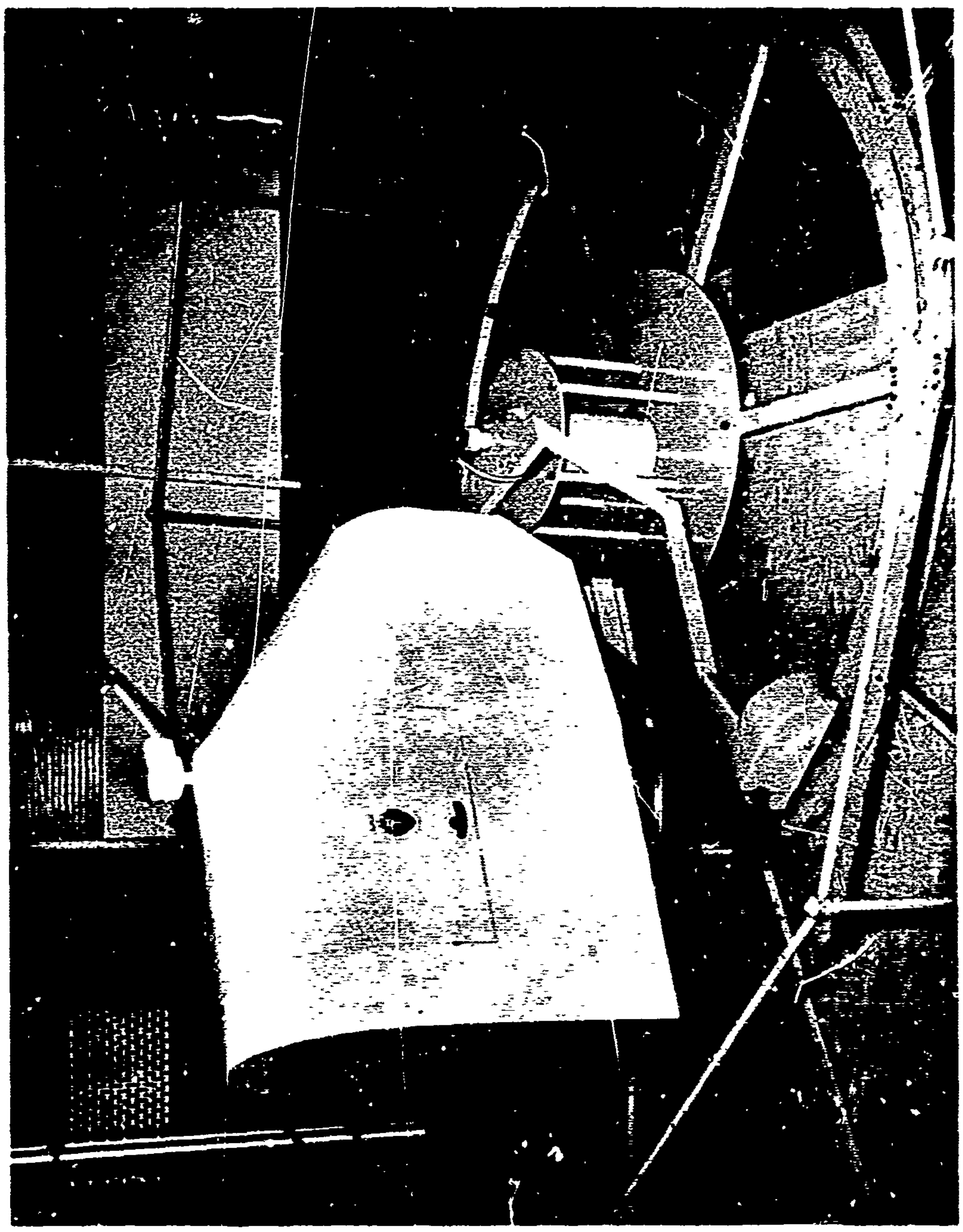

Fig. 1 The Spatial Disorientation Demonstrator.

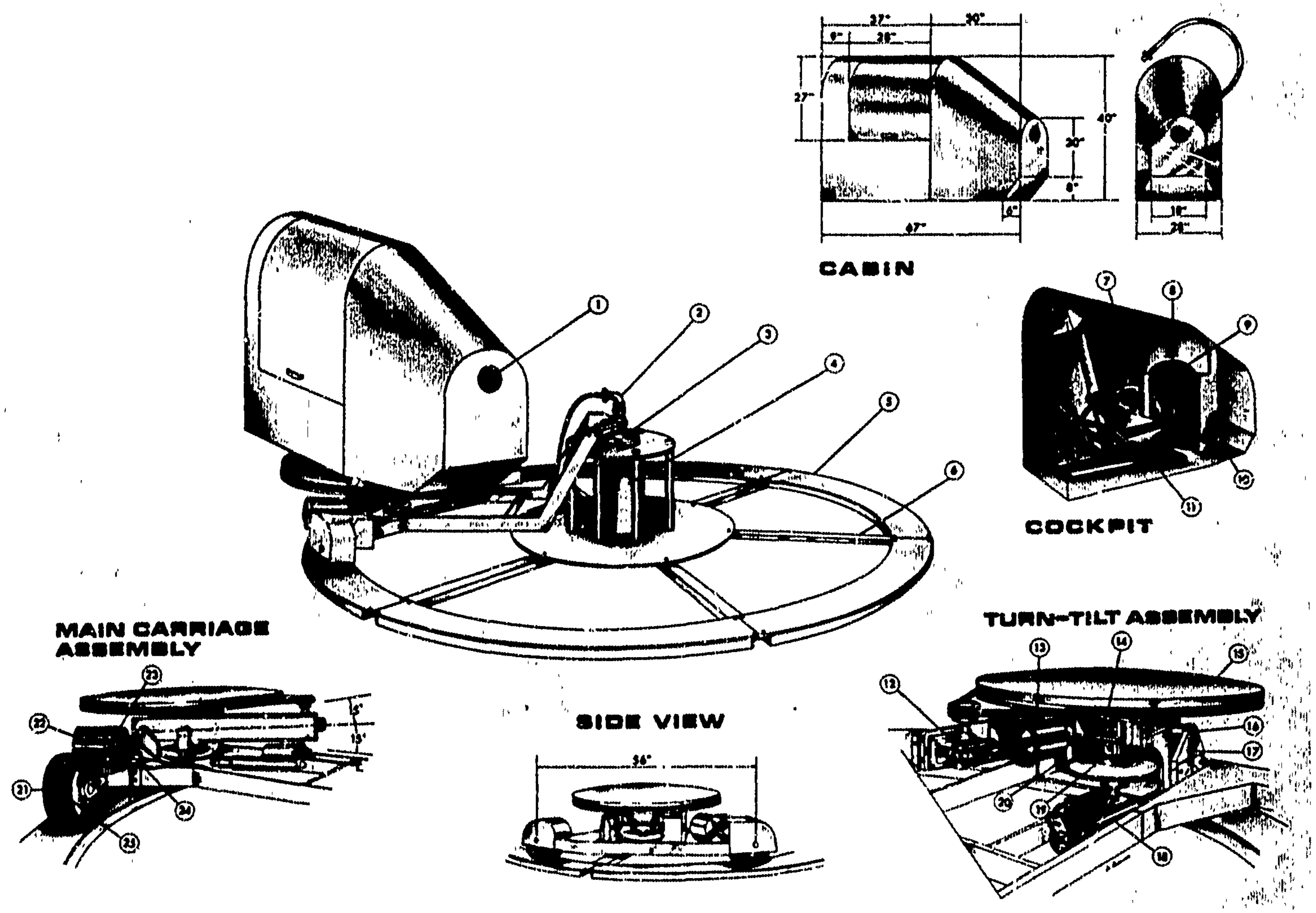

Fig.2 Details of construction of the SDD. The key to the numbers is available in SAM-TR-65-7.

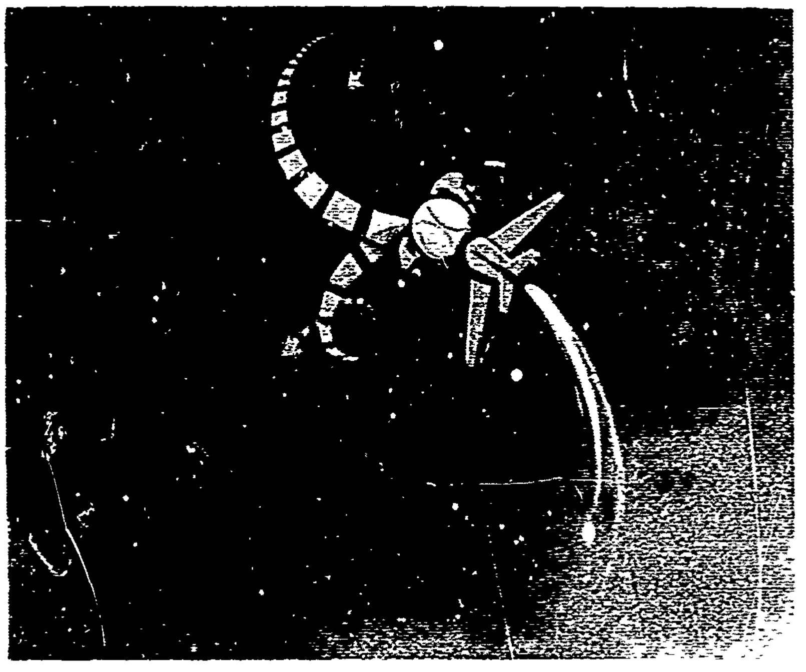

Fig. 3 The Coriolis illusion. If the pilot moves his head while in a prolonged turn, he may experience false sensations of violent changes of attitude.

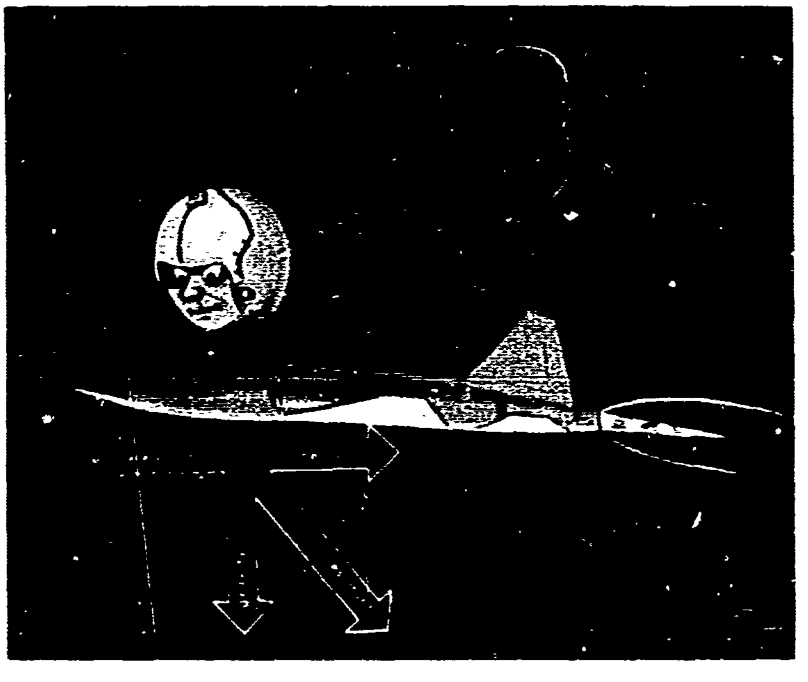

Fig. 4 The oculogravic illusion. As this high-performance aircraft takes off, the pilot may falsely perceive that the aircraft is in a steep climb.

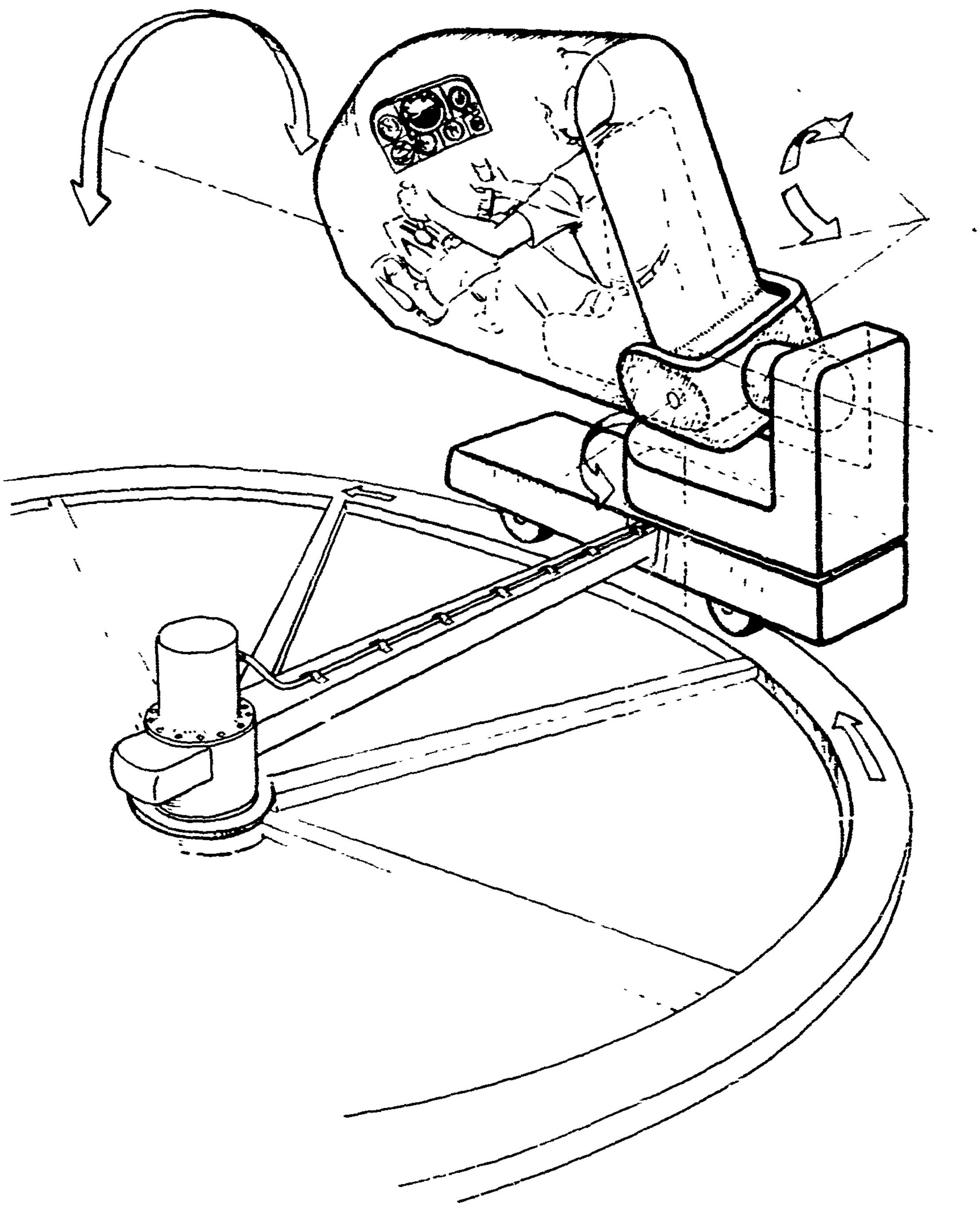

Fig. 5 The Spatial Orientation Trainer. The pilot riding this device can be subjected to the same illusions that the SDD generates, but he can "fly" the SOT by operating the control stick.

MEASUREMENT OF PERFORMANCE IN F-86K SIMULATOR

by

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SUMMARY

This paper presents an idea of how pilot performance could be measured and how a standardized flying program can be used to demonstrate the effects of extra work load and other "non-optimal" conditions upon performance.

Part (a) consists of the development of a standardized flying program. The pilot is supposed to intercept an enemy making an attack by means of radar under standard conditions. Eight pilots went through the program and a fairly good distribution of scores was obtained. (A correlation coefficient of 0.60 was found between the scores and level of pilot experience).

Part (b) deals with practice on the program. The effect of learning is a crucial point when scores of performance are to be compared under different conditions, and the pilots practised until they seemed to reach an individual optimal level.

Part (c) is concerned with the problem of how extra work load influences performance. To what extent is the optimal level of a pilot's performance reduced by adding some extra work load? As expected, there are individual differences, and the performance drop depends on what kind of extra load is introduced.

Part (d) is an experiment with one pilot flying the program under the influence of alcohol.

RESUME

L'auteur de cette communication expose comment mesurer les performances du pilote et comment utiliser un programme de vol standardisé pour mettre en lumière les incidences d'une charge de travail supplémentaire et d'autres conditions "non-optimales" sur l'aptitude du sujet à s'acquitter de sa tâche.

(a) Mise au point d'un programme de vol standardisé. Le pilote est censé intercepter à l'aide d'un radar, et dans des conditions normales, un ennemi se livrant à une attaque. On a soumis 8 pilotes à ce programme et obtenu une assez bonne répartition des points (coefficient de corrélation de 0,60 entre les points obtenus et le niveau d'expérience des pilotes).

(b) Pratique du programme. L'entraînement revêt une importance extrême lorsque l'on compare les points obtenus dans l'accomplissement des tâches assignées, dans diverses conditions, et les pilotes se sont entraînés jusqu'à ce qu'ils aient atteint un niveau individuel optimal.

(c) Influence d'une charge de travail supplémentaire sur l'accomplissement des tâches. Dans quelle mesure le niveau optimal de performance d'un pilote est-il réduit par l'addition de tâches supplémentaires? Les résultats varient évidemment, suivant les individus, et la baisse de rendement dépend de la nature de la tâche supplémentaire.

(d) Expérience consistant à faire voler un pilote sous l'effet de l'alcool dans les conditions prévues par le programme.

MEASUREMENT OF PERFORMANCE IN F-86K SIMULATOR

Dr Erik Riis

INTRODUCTION

Measuring the performance of pilots is important for several reasons. In the first place to get to know how the pilot candidates make progress during the training program. In other words, the measurement of performance might improve the selection procedure, which today is based upon subjective judgement by the flight instructors.

Secondly, a more objective measurement would result in better criteria for pilot performance, leading to more reliable validation studies, both for medical and psychological measures. This would imply an improvement of pre-flight pilot selection.

Thirdly, a testing of pilot performance might be a security aid. We should like to know how flying skill is maintained when exposed to different kinds of stress-producing conditions or after periods of absence from flying. A squadron commander once said he was always worried, as a pilot, during a "scramble" at night as he needed quite a bit of time before being fully awake. How did he really function in this almost sleeping condition? Testing performance might help a leader to learn what kind of strain pilot A and B can stand and what seems to reduce their skill in particular.

These goals will, of course, not easily be realized. In actual flying stress-producing factors can hardly be introduced, but to what extent can simulators support our endeavour? Even if most pilots prefer actual flying, and in spite of the fact that simulators cannot produce G-forces and anxiety, many aspects of flying proficiency may be tested in a simulator. If a pilot cannot manage a problem-loading flying program in a simulator, he would probably not be able to succeed in the air on a similar mission.

This paper deals with a pilot study on the measurement of performance under various conditions in a simulator. No definite conclusions can be drawn, so the main purpose of the presentation is to give an outline of the experimental design.

PART (a): DEVELOPMENT OF A STANDARDIZED FLYING PROGRAM

In planning the flying program we had these main goals in mind:

(i) The performance should be measurable in a plain and simple manner.

(ii) The task should be difficult enough to differentiate between pilots.

(iii) The task should be realistic in a way that pilots would find it interesting and become motivated for the job.

(iv) The scores should be correlated with some objective criterion of flying experience.

The experimental set-up in the whole task simulator was as follows.

The pilot went through a routine cockpit pre-flight check and, upon establishing radio contact with the experimenter, he was told to climb to a pre-selected altitude. The "warm up" period for the pilot before the actual test began was thereby kept nearly constant. Upon reaching the standard altitude the pilot was asked to establish the aircraft on a selected heading, maintaining a constant speed. As soon as this was accomplished the experimenter would "freeze" the simulator causing the instrument readings obtained to remain constant.

The experimenter could now place the target aircraft in the pre-calculated position on the control board. The target aircraft would then appear on the pilot's radarscope, in a 12 o'clock position. The speed, altitude and heading of the target would remain constant throughout the test. New the experimenter would freeze the entire plotting board until the pilot had obtained a radar lock-on and reported ready for the attack.

Upon clearance from the experimenter the attack was launched and the pilot's task from this point was to manouvre his aircraft in such a manner that the radar steering information was kept in the scope centre all the time, thereby indicating that the pilot was following a lead pursuit curve. Having flown a perfect pass the pilot should end up at a certain distance from the target after a pre-calculated amount of time. The attack was to be terminated by a firing burst.

The experimenter froze the plotting board when time was up and noted the position of the target and the attacker. Any inaccuracy in the pilot's pursuit manoeuvring would appear as a deviation from the pre-calculated ideal position. This deviation in azimuth and distance could be read directly from the plotting board in units of nautical miles. In the initial phase we considered the score recorded on a hit recorder as an additional check on the pilot's proficiency, but this was abandoned at an early stage.

The program consists of four runs - two right and two left pursuit curves - alternating between 4 and 8 miles launching distance. A single run from the 8 miles position takes 2 minutes and 38 seconds.

(The validity of the pursuit curve may of course be discussed from a tactical point of view but, having accepted this theoretical model as one way of doing it, a perfect sequence of responses to the steering information will bring the pilot to the "Ideal-Point", which is a very good starting-point for a final attack).

Apparatus Difficulties

The F-86K whole task simulator is a very complicated technical device. The layout is identical to the aircraft's and various malfunctions of the type encountered in actual flight operations did occur. Several small instrument errors were discovered during the standardization program and it was a rather painstaking task to find methods to eliminate or compensate these errors. However, as the program developed methods were found

enabling the experimenter to obtain reliable measures of actual flying precision. Our conclusion is accordingly that the following results are not influenced by errors in the measuring device itself, but are actual measures of the pilot's ability to fly the curve of pursuit under different experimental conditions.

Results

Eight pilots - well experienced with the F-86K aircraft - were tested on the standard program twice.

Table I indicates a moderate variation among the pilots. The maximum difference is 0.50 nautical mile on the test and 0.56 on the retest. The practical implication of this difference will be understood when it is realised that the maximum effective firing range is less than a quarter of a nautical mile in aerial gunnery.

We also find test reliability, as there is a correlation of 0.85 between test and retest scores, and there is no significant difference between the standard deviations.

In addition, the following conclusion can be drawn after this preliminary testing:

The flying performance is measurable in a plain manner on the plotting board, the scores being read in nautical miles from the ideal point.

The pilots accepted the program. They found it realistic and interesting.

A positive correlation (0.63) was found between test scores and total flying hours.

On the whole is seemed worth while to continue the project, though a lot of maintenance trouble and waiting time caused some difficulty with the administration.

PART (b): PRACTISING UP TO MAXIMUM LEVEL OF PERFORMANCE

As already mentioned the main goal of this project has been to find out how extra work load (lack of sleep, hangover and other non-optimal conditions) influence the individual pilot's flying performance. Before such conditions could be introduced, however, the pilots had to go through the standard program several times until they reached their individual limit. Having determined the maximum level of performance for the individual pilot, the effect of learning should be negligible, and any reduction of performance thus attributable to the special conditions imposed on the pilot in addition to the standard program.

Six of the original eight pilots participated in this practising phase of the project.

Results

Table II shows that only minor improvement takes place with practice and a variance analysis shows no significant variation between the different practising series.

In some cases the last result (score) is not as good as some of the previous ones. Having in mind the fact that the results can hardly be read with more accuracy than 0.05 nautical mile on the plotting board, we may say that the actual alteration in scores is negligible.

We may conclude that further practising seems to be unneccessary for this group of subjects.

(Table II gives some additional information. It is noticeable that the original moderate variation among the pilots has been reduced. This is very much caused by the fact that we are missing pilot No.7. Though the number of subjects this time is smaller we have to be aware that the effect of learning seems to reduce the inter-individual differences.

The program may, however, still be of use for our main purpose, i.e. to test the effect of different non-optimal conditions).

PART (c): REACTION TO NON-OPTIMAL CONDITIONS

In this phase of the project different types of extra work load were added to the standard program. Only two of these will be reported here.

(a) One attack was combined with the following radio transmission after having flown a control run:

"Echo 01. This is Gardermoen test. Your position is now over Bergen. State fuel."

"What is your approximate endurance at your present level?"

"Your fuel state is sufficient for another interception. After your final attack is completed proceed as follows: Turn immediately to 295°, and climb gate to fl 275. Scan for a target coming in from your starboard side. Increase speed as much as possible as this target's expected speed exceeds Mach 0.95. Check all switches on, as the target is identified as hostile.

Echo 01 read back essential information".

Results

There is a tendency to improve when extra work load is given in addition to the standard program. How could this happen? The most probable explanation is that the control performance without extra load has not been a maximum score. It is also possible that the experimental run got some "transfer" from the control run which took place immediately beforehand.

From a flying safety point of view, however, it is more important to investigate why the other two pilots show a drop in performance. The large deviation for pilot No.4 is caused by misunderstanding of the instruction. Instead of waiting until the attack was completed he turned immediately to heading 295°. His score might have been rejected. Though the scores of the control run are rather bad for pilots 1, 2 and 3, the results obtained in the experimental situation seem to be quite normal.

It is, in my opinion, safe to conclude that their performance has not been reduced by this kind of extra load.

Pilot No.4 has drawn some suspicion on himself by "misunderstanding" the instruction, but this detail reminds us to be very cautious with our instructions.

(b) Another attack was launched together with eight arithmetical problems, for instance: 7 x 12 and 18 x 21.

Results

Taken as a group, and using the means, there is no significant difference to be found between the control run and the experimental situation. Looking at the individuals, however, we get another picture. Pilot No.4 is the only one who seems to be unaffected by the arithmetical problems, whil pilot No.2 seems to have been heavily disturbed.

In evaluating the scores it should be taken into account how the pilots succeed with the mental problems. Answers were given to all items, but some answers were wrong. It is of importance to record that pilot No.2 made more errors than the others, a fact which places him specially into the focus of our attention.

The problems given in this second run are not a part of usual flying performance. It was expected beforehand that this phase of the program would cause the most severe difficulties. New and unexpected problems with some difficulty were supposed to produce more stress in the pilot and could in our opinion be compared with an emergency situation, which is almost impossible to simulate realistically.

PART (d): PERFORMANCE UNDER THE INFLUENCE OF ALCOHOL

In this part of the project pilots were supposed to fly the standard program under the influence of alcohol and later repeat it in the hangover phase. Due to administrative and ethical problems the experiment was done with only one pilot under the following conditions.

After having flown the program under normal conditions the pilot drank nearly half a bottle of gin in the course of half an hour from 9.30 p.m. At 10.30 he went through the program again, and immediately afterwards he was observed by the physician. who stated that the pilot was in high spirits and talked excessively, but with normal articulation. He did not seem to be definitely intoxicated when the doctor examined his memory, his concentrating capacity and motor coordination. At 11.00 hours the concentration of alcohol in the blood was found to be 1.07 per mille.

At 11.15 the pilot drank the rest of the half bottle of gin and the doctor brought him a pint of strong beer. At 11.45 he flew the program again and at midnight the physician examined him a second time. The pilot now gave an immediate impression of being intoxicated and his speech was slurred. His balance was not too good, but his mental capacity seemed fairly intact.

The next morning at 9.30 the pilot was awakened and he went through the program again. He now suffered from headache and felt dizzy and in bad shape. Alcohol concentration was found to be 0.50 per mille at 9.45 a.m.

Results

The table shows that the pilot performed surprisingly well during intoxication. The next morning, however, there is a more marked drop in his score. These findings indicate that the hangover period may be as dangerous as a moderate intoxication state, though these single results are observation only. The rather bad result in the morning was obtained after 9 hours of abstinence and with an alcohol concentration so small that one probably would have been acquitted of a possible charge.

CONCLUSIONS

There is no basis for drawing far-reaching conclusions on these "pilot-pilot-studies", which have been carried out on a very small sample.

We have learned that even a rather simple flying program in a simulator gave a lot of technical difficulties. This could, however, be overcome by help of skilful technicians and patience.

The selected standard program seems to have been a little too easy for well experienced pilots, though a fairly good variation among individuals was found in the initial phase. The program proved to be quite reliable as a test and the performance could be measured in a simple manner as a deviation from an ideal point expressed in nautical miles. The pilots found the program realistic and interesting, and a positive correlation was found between test scores and total flying hours.

When extra work load was introduced the pilots responded differently as expected. Extra load of a routine character did not reduce performance as did new and unexpected problems in some subjects.

One pilot exposed to alcohol had quite a good score with an alcohol concentration of 1.07 per mile, but he was less successful in the hangover phase about eight hours later.

In spite of obvious technical and administrative difficulties it might prove worth while to develop an experimental design on simulators with a somewhat adjusted flying program.

TABLE I

Deviation From The Ideal Point For Test And Retest (Nautical Miles).

Pilot No.	*Test*	*Retest*	*Difference*
1	0.40	0.28	-0.12
2	0.64	0.48	-0.16
3	0.41	0.26	-0.15
4	0.43	0.57	+0.14
5	0.36	0.27	-0.09
6	0.35	0.37	+0.02
7	0.85	0.82	-0.03
8	0.44	0.28	-0.16
M	0.49	0.42	
S	0.16	0.19	

TABLE II

Deviation From The Ideal Point For Different Practising Series (Nautical Miles).

Pilot No.	*1st series*	*2nd series*	*3rd series*	*4th series*	*5th series*
1	0.40	0.28	0.31	0.27	0.30
2	0.64	0.49	0.44	0.34	0.43
3	0.41	0.26	0.44	0.32	0.41
4	0.43	0.57	0.29		
5	0.36	0.27	0.36		
6	0.35	0.37	0.42		

TABLE III

Performance With And Without Extra Work Load. Radio Transmission.

Pilot No.	Deviation without extra load (n. miles)	Deviation with extra load (n. miles)	Difference (n. miles)
1	0.66	0.13	-0.53
2	0.58	0.34	-0.24
3	0.56	0.47	-0.09
4	(0.10)	(1.27)	(+1.17)
M	0.60	0.31	

TABLE IV

Performance With And Without Extra Work Load-Arithmetical Problems.

Pilot No.	Deviation without extra load (n. miles)	Deviation with extra load (n. miles)	Difference (n. miles)
1	0.09	0.40	+0.31
2	0.63	1.51	+0.88
3	0.44	0.58	+0.14
4	0.19	0.19	0.00
M	0.34	0.67	

TABLE V

Performance With And Without Alcohol.
(Deviation In Nautical Miles)

Without alcohol	With alcohol (10.30)	With alcohol (11.45)	Next Morning
0.32	0.45	0.27	0.56

MEASURING THE PILOT'S CONTRIBUTION IN THE AIRCRAFT CONTROL LOOP

by

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SUMMARY

Engineers and designers are continuously aware of the need to specify the form of the pilot's input to an airborne weapons system, if good design guidelines are to be obtained for research and development purposes. Unfortunately, the fact that the biological sciences frequently have to deal with more complex material than do the physical sciences means that human factors workers are often not prepared to propose or accept a closely quantified description of human control function. In particular, individuals are known to differ between themselves in piloting skill and controlling strategy, and any given individual can vary widely over time, in poorly understood ways which are apparently the result of interaction of an embarrasingly large family of factors.

During research in simulated flight over the last 2 years, the author has been at pains to develop measurement techniques which do not obscure inter-pilot differences in manual control style, but which, at the same time, reduce the data to manageable proportions. On the basis of this research, it is proposed that pilot control strategies may be considered, to a first approximation, as a function of four primary inter-related factors. These are: (1) the ability to erect and test alternative decision hypotheses; (2) the amount of information felt to be required to reach decision; (3) the perceived urgency of decision; and (4) the sense-data available in the situation for sampling and decision modelling.

RESUME

A tous les stades les ingénieurs sont conscients de la nécessité de spécifier la forme que revêtent les ordres donnés par le pilote à un système d'armes aéroporté, si l'on veut obtenir des principes directeurs valables dans le domaine de la recherche et des réalisations. Malheureusement, du fait que les sciences biologiques doivent fréquemment couvrir des domaines plus complexes que les sciences physiques, les chercheurs traitant des facteurs humains ne sont pas prêts, bien souvent, à proposer ou à accepter une description rigoureusement quantifiée de la fonction humaine de contrôle. On sait, en particulier, que les individus diffèrent entre eux du point de vue de leur compétence en matière de pilotage, et de leur façon d'exercer les fonctions de contrôle, et que, d'autre part, un même individu peut varier considérablement dans le temps, suivant des processus encore mal compris et dans lesquels un nombre déconcertant de facteurs entre en jeu.

Au cours des recherches poursuivies ces deux dernières années à l'aide de vols simulés, l'auteur de cet exposé s'est appliqué à mettre au point des techniques de mesure qui, sans annuler les différences de style de contrôle manuel entre les pilotes, réduisent les données à un nombre commode. Sur la base de ces recherches, il propose, en première approximation, de considérer la "stratégie" de contrôle qu'applique un pilote comme étant fonction de quatre facteurs essentiels et intimement liés: (1) l'aptitude à établir et à essayer des hypothèses de décision alternatives; (2) la somme d'informations apparemment requise par la prise de décision; (3) l'urgence de la décision, telle qu'elle est perçue; (4) les données relatives aux sensations dont on dispose dans la situation en cause en vue d'un échantillonnage et d'une élaboration de décision.

MEASURING THE PILOT'S CONTRIBUTION IN THE AIRCRAFT CONTROL LOOP

H.P.Huddleston

1. INTRODUCTION

Classical psychophysical experimentation, seeking to generalise about the central tendencies of human behaviour, has always been encumbered by inter-subject differences. So unremitting has this encumbrance been that whole topics such as intelligence, aptitude, and personality testing have developed to concentrate on little else. The problem is still with us in aviation. Almost every engineer has at some time wildly hoped that *this* pair of pilots, at last, would agree that such-and-such a system was easy to fly.

It would be extremely convenient, to say the least, if the manner in which all pilots transferred information from a specified set of displays to a specified control system could be described mathematically. Early over-naive attempts to adopt linear servo theory descriptions wholesale have developed cautiously into limited formulations of prescribed application. Some models, notably those mapping second-order compensatory tracking of a random-appearing 1-dimensional visual display by experienced operators over short runs, are becoming so refined as to permit the study of possible non-linear descriptions (such as sampled-data ones). It goes without saying that the remnant term outside the basic linear describing function frequently accounts for > 50% of the total power put out by the operator.

Inter-pilot differences in manual flight control activity thus represents a vitally important research area. The first systematic study was conducted at Cambridge, England, during the early and middle years of World War II (Refs. 1, 5, 6, 8). One experiment of a series studied the modulus integral elevator and aileron position of 355 pilots flying a 40-min set of simple manoeuvres in a fixed-base fighter simulator. 59 pilots were classified as "overactive" on the basis of their large control activity scores. They were tense, anxious, excited, irritable and equipment-blaming, and felt the correction of flight path errors to be urgent. Their early steady ripple of fine control movements deteriorated over time into large, irregular and over-compensating ones. An association was drawn between their behaviour and that of patients, diagnosed as anxiety states or obsessionals, used in subsequent experiments. At the other extreme, 28 pilots were classified as "inert" since they demonstrated small control activity scores. They were content to allow large errors to persist for long periods, lost interest and concentration over the course of the run, and were apathetic, discouraged and self-blaming. There was some association with the behaviour, in later experiments, of patients diagnosed as conversion hysterics or exhibiting withdrawal symptoms. Since this valuable research, little systematic investigation of individual pilot control styles appears to have been conducted until the late 1950's.

2. RESEARCH OVER THE LAST 15 YEARS

A number of workers have produced valuable data in the course of research investigating either pilot transfer functions, or autopilot models attempting to include their theoretical dynamics. The Goodyear Corporation[12], while investigating the effects of simulator cockpit motion cues, occasionally gave system control to a network simulating pilot dynamics without actually telling the pilot. "Active" pilots, who made frequent stick motions, took up to 30 sec to realize; "Passive" pilots, who were more cautious and therefore less linear, noticed that control had been withdrawn from them after only a few seconds. While both pilot groups achieved nearly the same levels of r.m.s. pitch or roll axis error, substantial changes in network gain and deadspace had to be made to simulate their different dynamics. Hall[13], studying 2 pilots handling different light aircraft longitudinal dynamics, measured average absolute stick deflection (which he converted to average pilot force linearly). There were small observed differences between the 2 individuals, while control activity generally increased with controlled element gain. Publishing in the same year, McRuer and collaborators[21] studied the dynamic response of 6 naval and 2 civilian pilots flying the same type of light airplane, and also performing simulated flying tasks in that airplane parked in a hangar with a computer driving the instruments. The only naval pilot with previous experience (of the relevant air-to-air radar-controlled gunnery) used aggressive and extreme control application, resulting in highly non-linear relay type operation and exhibiting high gain relative to the other pilots. Variability between runs for a given pilot was of about the same order of magnitude as the variability of individual pilot means about the grand pilot average. The flight situation, which gave pilots whole-body acceleration, more instruments, and probably real apprehension to attend to, gave rise to dynamic responses differing from those measured in the hangar simulation in both longitudinal and lateral reaction time and gain. More recently, Tremblay and co-workers[29] showed, by comparing power spectral density analyses of elevator and aileron surface deflections in flight with those in static and dynamic centrifuge simulations, that high frequency power components were successively reduced static to dynamic to flight. Lastly in this group, Demaree and colleagues[7] theorised that control movements and opinion should both relate to the effort demanded by different aircraft dynamics. Their 3 pilots, flying a sequence of 6 manoeuvres in a fixed-base fighter/bomber simulation, showed individual differences in correlation (generally intermodiate in magnitude, $r = 0.55$ to 0.88) between elevator activity and height and pitch angle performance, and (generally good, $r = 0.73$ to 0.97) between elevator activity and pitch rate. In terms of lateral performance parameters, there were similar inter-pilot differences in correlation (generally low to intermediate in magnitude, $r = 0.02$ to 0.57) between aileron activity and heading and bank angle performance, and (generally good, $r = 0.67$ to 0.89) between aileron activity and roll rate. Of all parameters measured in mean squared error and absolute error for comparison, the lowest corrolation between 13 longitudinal measures ($r = 0.98$) was for one pilot's elevator position score and the lowest between 11 lateral measures ($r = 0.81$) for another pilot's aileron position.

A second major group of recent investigations which have contributed useful data has been concerned primarily with aircraft handling qualities, including the adverse effects of turbulence. Brown and Johnson[3] studied 2 test pilots performing a simulated close-formation flying task, using various longitudinal damping/stick force per g settings. One pilot, who used an aggressive control action referred to as a "desperation technique" was equally good whether cockpit pitch motion was added to the basic large heave motion or not. Rawson and Brugh[24] and Solidey and Schohan[28] both studied simulated low-level

flight through turbulence. Both concluded that controls for such a flight mode should require fine movements (as with a joystick) rather than large ones (as with a conventional centre column) to overcome some of the mechanical disturbance of manual control by vertical buffeting. Perry[23] studied stability and control variables in static and dynamic aircraft simulations. He concluded that body motion allows pilots to achieve stability (after disturbance by, for example, a lateral gust) more quickly and with more economic aileron usage, and observed that some pilots chatacteristically utilise many rapid control movements (occasionally of very high amplitude, tending to divergent over-controlling) while some are noticeably more leisurely in style. Ragland and collaborators[25] exposed 10 airline and 5 in-house pilots to static and dynamic centrifuge simulations of severe airline jet upsets in clear-air turbulence. On first experiencing negative g (-gZ) initial stick movement in the wrong direction was the rule rather than the exception. Control activity differed widely between pilots, was unrelated to specific periods of high turbulence, and was at a higher level in dynamic than in static simulation. Most recently in this group, Perry and Burnham[24] and Wempe[30] studied pilot performance in simulations of relatively high vertical acceleration environments. The former demonstrated that 2 of his 10 pilots, employing current rough air flying techniques involving limited attitude changes, employed small and gentle elevator inputs to achieve easy limiting of airspeed, pitch and vertical speed excursions. Elevator activity traces showed marked differences in the number and size of inputs following the first large vertical updraught. The latter concluded, from his study of 3 pilots performing a height-clearance task, that cockpit (heave) motion exerts its largest effect during practice, when it eliminates any tendency to over-control.

A third class of research has considered serial changes in performance over time, as a result mainly of learning or fatigue. Fuchs[11] studied 5 subjects performing 1-dimensional compensatory tracking, and arranged for a computer matching of each operator's output (by determining the weightings of gains in the error position, error rate, and error acceleration terms which the operator utilized). As learning progressed, operators responded increasingly to error velocity and acceleration components, reverting to a reliance on error position as skill regressed. Cacioppo[4] reached supporting conclusions from his study of the analog model matching of 5 jet pilots, 3 light plane pilots and 1 non-pilot. Pilots of limited experience used error rate as an important determiner of control behaviour, while error acceleration was only of importance to highly experienced jet pilots. In work aimed at investigating pilot fatigue in long-range transport flight, Hartman and Simons[14] studied 64 sec epochs of integrated control rate from 4 pilots each flying a simulated 24-hour flight. Performance deteriorated insignificantly and there was no decrease in control activity over the course of the run, contrary to expectation. Naylor and co-workers[22] studied 128 Ss performing 3-dimensional tracking (but using rate control, which is known to give rise to essentially different behaviour from that using acceleration control as in aircraft) and displayed integral control motion to them as a "fuel consumed" parameter. Initially there was large variability in activity, which levelled off, followed by a decrease as practice accrued. Lastly, in this section, Ruocco and colleagues[27] examined the improvement with training of 12 experienced pilots executing simulated carrier approaches in a cockpit with or without motion cues. Pilots did not exhibit a significant improvement in mean or r.m.s. elevator or aileron displacement (compared to the established optimum stick position for the approach) in either static or dynamic training, although pilots trained in the static cockpit eventually improved their elevator performance on being tested in the dynamic simulation. In general, there was greater variability of control application by pilots working in the static cockpit. Analog traces of r.m.s. stick position showed noticeable

differences between some pairs of pilots during pair-matching runs, which persisted perhaps more readily through static than through dynamic training, being apparently more marked for aileron than for elevator activity.

Fourthly, work by Elam and Abbott[10] in connection with 5-axis motion simulator evaluation of displays for VTOL aircraft is relevent. It was reasoned that control activity is important since it represents, of course, the pilot's only permitted response, signalling how satisfied he is with his performance in the system. A score combining control input and measured error was therefore sought. Integrated error divided by control rate proved to be a useful score of efficiency, while error divided by control acceleration demonstrated less day-to-day variability, and error divided by control jerk proved even more stable. There were almost always larger between-pilot than within-pilot variations in control usage, however[9].

3. RECENT RESEARCH AT IAM

Of a range of laboratory equipment and aircraft available, 2 fixed-base simulators were chosen with which to begin research in the general area of inter-pilot differences in manual control. One simulator (SARO) is aerodynamically very simple, so that non-pilots can be cautiously included in some experiments, and contains 7 basic flight instruments plus a CRT director. It is normally set up to represent a stable, medium-performance single-seat fighter. The other simulator (Minerva) is aerodynamically very complex, and incorporates an advanced electronic projected windshield display associated with future high performance fighter/bomber concepts.

The first experiment[15] sought to investigate pilot acceptability of the simplified aerodynamic characteristics set up for this work in the SARO facility. The simulation proved worthwhile, and has been retained throughout the subsequent related trials. Two flying doctors and two test pilots each flew a 55 min height-changing task, their various performance parameters being recorded on a 14-channel FM tape machine. Modulus integral elevator and aileron position was found to be a useful indicant of operator effort when sampled every 8 sec, and clearly showed differences between the 4 individuals which could not be related simply to flying accuracy achieved.

Next[16] a test pilot, a squadron pilot, and a non-pilot known to be competent in the SARO simulator, were required to follow random-appearing directed manoeuvres in height and heading simultaneously. Elevator and aileron activity beyond arbitrary thresholds was integrated without regard to sign, and recorded over 10-sec epochs. An analog circuit was patched up to give, from tape replay, the number of such control movements in each sample, their mean duration as a percentage of epoch length, and their mean amplitude. The test-pilot, an apprehensive individual who subsequently became personally very involved in the results when he knew his performance had been minutely scrutinized, achieved the best overall performance by maintaining a constant stream of small-duration control movements near stick centre. Pilot and non-pilot achieved a highly satisfactory level of performance, remarkably similar to each other. The pilot, compared to the test pilot, used generally higher amplitude excursions of longer duration, inserted less frequently. The non-pilot, who was a junior scientist well above average intelligence but who had been deprived of all knowledge about the implications of vigorous control inputs in a dynamic flight environment, used arduous near-random switching control movements of high amplitude and duration.

The following experiment contributing data of interest[17] partly replicated the previous one, calling on a different squadron-pilot and non-pilot, plus 5 excellent pilots (students on a test pilot course) and 3 test pilot instructors to the course. Each was allowed to familiarise with the simulator for 15 min, after which he flew a sequence of manoeuvres (presented as instructions on a roller knee-pad) lasting 23 min (median). A count was made of the number of displacements and the time spent beyond arbitrary control thresholds (elevators ±9% and ±16% of full scale, ailerons ±5% and ±12%). Elevator activity was generally significantly correlated between familiarisation and experimental period (r = 0.66 to 0.83) while aileron activity was not (r = 0.35 to 0.53). Those pilots who had used the more vigorous elevator inputs responded more slowly and less reliably to light or voice warning signals. Apart from this, there was no significant or even suggestive relationship between run (tracking) performance and control style which held for the pilot group as a whole; such a finding would certainly wreak havoc in most contemporary attempts to formulate pilot transfer functions claiming generality. The experimenters took great delight in watching the TV monitor and real-time 16-channel trace record of one student test pilot in action. He was very intelligent and insightful, and the experimenters, free of that pre-experimental reserve essential to provide standard treatment to each operator, enjoyed a most rewarding debrief discussion. Subsequent hybrid analysis methods revealed that his height performance could not be faulted for 9.8 min of the familiarisation period (which time had included 5 × 180° heading changes at constant demanded airspeed) during which his elevator and aileron displacements never exceeded ±10% or ±6% of full scale, respectively. He maintained a constant "dither" of fine control inputs near stick centre whether any instrument error was displayed or not. Incidentally, the 3-operator distinction observed in Reference 16 was supported in the present investigation, which used different operators, measures, and task demands.

Two further experiments[18,19] studied the modulus integral elevator and aileron control position of pilots performing directed navigation and attack manoeuvres, using variations in the design geometry of a projected windshield display (in the more complex Minerva simulator). Eight squadron pilots participated in each phase, those in one phase having a substantial background of naval attack flying, those in the other being even more experienced in long-range bomber duties. None of the dispaly element changes affected control activity, which was shown, by analyses of variance, to differ significantly between the pilots in each group. Correlations between mean elevator activity and mean elevation error ranged from r = 0.020 to 0.796 over the 16 pilots as a whole, and those between aileron activity and heading error r = 0.208 to 0.556. There were no significant correlations between the control activity of individual pilots and either the scatter of light signal acknowledgement times, or the slope of learning curves representing simulator familiarisation time, or their total hours flying experience. Quadratic regressions showed an insignificant decrease in control motion over the whole experiment (24 or 32 runs per pilot).

The most recent piece of work which has treated control input style as a measure (20) required 24 members of IAM technical support staff to learn to fly a directed CRT task (one sinusoid in height, one in heading) in the SARO simulator. Control position measures as in Reference 16 were used. Eight of these subjects were selected on the basis of similarity of performance achieved at the end of one hour, and given further testing for intelligence (Raven's Advanced Progressive Matrices (MAT)), sensory receptivity (Archimedes Spiral after-effect (SAE)), impulsiveness, neuroticism and sociability (Eysenck Personality Inventory (EPI) and risk-taking (Kogan and Wallach Choice Dilemmas (CD)). Apart from the similarity in height and heading performance which they had

eventually reached, they were markedly different individuals in terms of educational achievement, rate of learning to control and halt vertical and turning speed of the simulator, and apparent understanding of the nature of acceleration control. In particular, there were 2 individuals who more or less instantly elected to use fine control inputs, 2 who even at the end worked very hard in terms of extravagant over-controlling, and 4 who reduced the size and increased the frequency of elevator inputs (at various rates) over the course of an hour. When this simple classification into three groups is accepted, findings with respect to intelligence and personality test results are still not clear cut. At least, those 2 individuals who failed to reduce stick input magnitude were found to be (relatively) low in intelligence (MAT) and receptivity (i.e. were "short judgers" of SAE). In addition, there was some suggestion (statistically insignificant, which is hardly surprising when such small groups are subdivided) that those operators who were more cautious (EPI, CD) either made small control inputs initially or as soon as they understood the acceleration control system.

One experiment at IAM is interesting, since physiological indicants of autonomic arousal and subsidiary task measures of spare mental capacity were taken, but may not be directly relevant since the control system was only 1st order (rate)[2]. 8 pilots and 8 non-pilots performed compensatory one-dimensional tracking, with and without the requirement to attend to a second (light cancellation) task. A count of the number of rate inputs each operator made showed that the pilots actually made more control decisions than the non-pilots, congruent with their better performance, and both groups made less when their limited attention had to be shared over the two non-combinable tasks. No consistent relationships between control usage and physiological arousal were apparent (leg and arm EMG, GSR, and tidal PCO_2, O_2 minute volume, peak flow, respiratory rate).

4. BROAD SPECULATION

What conclusions can be drawn from this research? What avenues suggest themselves for future research? Certainly the evidence to date is hardly more than fragmentary, especially since most of the investigations quoted were primarily attempts to understand skilled behaviour in general, rather than inter-operator differences as such. Let no one doubt that the bulk of relevant research still needs to be done.

Starting from very basic principles, it can be said that the fundamental activity of organisms is to organise, to restrict the variety of information transmission in the cybernetic sense, so as to survive over time. Man, the highest organism known, sets himself above other organisms by his ability to organise mentally. He organises sense-data into mental models (mapping some aspect(s) of the universe) which can be manipulated to predict the outcomes of possible events or actions. A basic need to model, to pattern, spills over into all aspects of human life (art, science, social order) even when no threat to survival is present. Hence any comprehensive theory dealing with inter-operator differences in skill is going to have to be very broad-ranging in interest. Several hypothetical model-building variables have been named in intelligence and personality testing and theory to date, most of them complex if not competing. It is most difficult, therefore, to decide even in any intuitive way which variables naturally cluster into larger factors; it is, however, impossible to decide analytically. There are therefore two major warnings, firstly, that this problem area is poorly understood, and secondly, that the following discussion may be more informative about the author than about the topic.

My basic assertion is that the way in which an operator sets about controlling a process should depend on his total grasp of the uncertainties of the process and his ability and need to resolve them. There would appear to be four outstandingly important factors involved. The first is the individual's ability to build and test a number of models, a range of decision hypotheses, each attempting to represent the situation. The second is the total ensemble of uncertainty available to the individual for decision modelling, the information at his disposal in terms of sense-data. The third is his latency of decision, the time and modelling effort he characteristically expends before accepting a specific decision model with all its implications committing the organism to action. The fourth is the typical felt urgency of decision, the idiosyncratic need for certainty. Clearly, these four hypothetical factors overlap somewhat, and interact to a great extent. They do not include muscular dexterity, nor any description of the variables which an operator is trying to compromise (such as arm effort, fuel consumed, time taken, etc) while performing a specified task.

The ability to build and test patterns to describe events has been noted in experiments on anticipation in tracking, and has long been postulated as a general intelligence factor. Classical tests measure it by noting how many test problems an individual can solve from a group. More recently, creativity tests have been developed to give credit for the number of possible solutions attempted. There is some inconclusive evidence that the readiness to reject a useful model in preference for a novel one falls off with age. Rigidity, as this has been called, is often related to intelligence but may not be a unitary factor at all.

Experience, or long term memory, is one determiner of the amount of information available to the operator for modelling. Short term memory, especially recent practice on the test equipment forming part of the investigation, will also be important. It is known that people vary widely, both in how available their memory stores are, and in how accurate their short term recall is in particular. This latter memory certainly deteriorates with age, while the useful data in the long term one probably increases. Hence a typical finding in aging studies is that learning of a novel skill may be slower for older operators but that this is offset by the greater relative experience they can call on. A second aspect of recent memory concerns fatigue or loss of motivation. An operator will normally be unwilling to devote continuous close attention to events which are familiar or relatively unchanging. They present no challenge to his ability to model, so cannot be a threat.

The information currently available to the operator from the control situation will also be important. Three important examples include the effects of system lag, of the type of tracking system used, and of cockpit motion. Ideally, a system with no perceptible lag gives the operator immediate knowledge of the results of his control input. Some lags (of the order of seconds) are compatible with the characteristics of human memory and can thus be dealt with, but will present more difficulty to some operators than others. Tracking systems are generally designed to be wholly pursuit (in which the operator controls one display element to follow another which is system driven) or wholly compensatory (in which both the operator's and the system's inputs move one element with reference to a fixed datum). The former offers the operator more information about the system's error forcing function, and is hence generally easier to learn and use. Cockpit motion produces two main effects, one helpful and the other disturbing. Rotations in pitch ($\ddot{\theta}y$) and roll ($\ddot{\theta}x$) can give a fast, useful indication that a manoeuvre has been initiated or that an uncontrolled-for out-of-trim condition has arisen. Non-pilots

learning to track in a fixed-base simulator do not appreciate the substantial acceleration forces which their initial aggressive control technique would produce in a realistic environment. The disturbing effects of motion are most frequently felt in heave (g_Z) during terrain-following or flight through turbulence. Here it is not primarily control activity which produces the acceleration environment, but the environment which interferes mechanically with manual control.

Decision latency, or delay in making a decision upon which to act, is thought to be a stable characteristic of individuals. Anecdotally, some individuals are impetuous (and perhaps aggressive) while others are cautious (and perhaps retiring). Investigations of sensory receptivity show that a given individual gives stimulation a characteristic weighting. He will adapt to a regular environmental change to a consistent extent, will monitor his own internal sensations for a consistent period, will be prone to travel-sickness fairly reliably or not. There are indications that pain tolerance, the readiness to accept reassurance from social agreement, and the number of times a relationship must be repeated before it is accepted as having predictive value are also related. Perhaps the mean sampling frequency of a time-varying information source is also idiosyncratic in this way, as well as being a function of source bandwidth. Decision latency is certainly a problem area to which more applied human factors research should be directed. It may not be a unitary trait at all, for example, or may even subsume the basis of risk-taking behaviour.

The need for certainty typically displayed by an individual has a respectable theoretical history in the study of motivation, anxiety, and neuroticism. Motivation is usually held to break down into two aspects, the basic drive level of the individual (arousal) and learned drive habits towards or away from specified stimulus ensembles. Certainly individuals differ in basal arousal, and in the effects of stress (in the sense of concern for one's ability to adapt) on arousal. Also, learned habits will depend on an individual's experience; he may have been generally rewarded by seeking social approval, for example, so that he might exercise his skill best in the presence of peer figures. Anxiety, more in the classical sense of tolerance of ambiguity or cognitive dissonance reduction, can be shown to vary between individuals by relatively simple tests. Its relationship to neuroticism is unclear. Neuroticism, in fact, is usually treated as a quite separate personality trait which may generate a drive for certainty only when some non-conscious want is challenged. Again, the importance of this area (if it is a single area) for applied human factors work cannot be evaluated without more direct research.

In summary, four families of psychological variables have been suggested as accounting, to a large extent, for observed inter-operator differences in manual flight control strategies. Given that the pilot population is selected from the general population, and the test pilot population further selected still, one can assume that a mean control style characteristic of each, if meaningful at all, will not be the same for all three. In practical terms this means two things. Firstly, squadron pilot behaviour cannot be wholly represented by simulator-competent non-pilots or by test pilots. Secondly, experimental subject populations smaller than about 6 to 12 (depending on skill level, objectivity of measures, and generality required of the findings) can yield highly subversive data. Certainly, this is a most difficult research area in which to progress.

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PRIOR LEARNING AND AGE IN RELATION TO PILOT PERFORMANCE

by

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*The views expressed in this paper are those of the author and do not necessarily reflect the official views of the Canadian Forces.

SUMMARY

An attempt is made in this paper to break away from the traditional emphasis by psychologists and others on the establishment of arbitrary selection, training, and performance standards for pilots. As important as they are, they are essentially negative in nature. If we are to enhance learning during pilot training, reduce flying accidents, and improve the operational effectiveness of pilots, our research effort cannot be restricted to the prediction of pilot performance but must move on to a more positive emphasis on the modification of pilot behaviour through training. To accomplish this aim we must strive for a better understanding of the complex variables which account for the wide range of individual differences found in the assessment of pilot skill.

Some of the effects of two of these variables, prior learning and age, on pilot performance and flying accidents are discussed. Supporting evidence is drawn from the extensive experience of the RCAF in the training of Canadian, NATO, and other foreign national pilots.

RESUME

Dans cet exposé, l'auteur s'efforce de se dégager de l'importance donnée traditionnellement, en particulier par les psychologues, à l'établissement de critères arbitraires de sélection, d'entraînement, et de performance. En dépit de leur valeur, ces critères sont de nature essentiellement négative. Si nous voulons relever le niveau de l'instruction dispensée au pilote au cours de son entraînement, réduire les accidents de vol, et améliorer le rendement opérationnel des pilotes, nous ne pouvons limiter notre effort de recherche à la prédiction de la capacité fonctionnelle du pilote, mais nous devons faire ressortir de façon plus positive les modifications de comportement amenées chez lui par l'entraînement. Dans ce but, nous devons nous efforcer de mieux comprendre les variables complexes sur lesquelles reposent les nombreuses différences individuelles que l'on découvre lorsqu'on évalue la compétence d'un pilote.

L'auteur analyse certains effets, sur la capacité fonctionnelle du pilote et les accidents de vol, de deux de ces variables: l'instruction antérieure et l'âge. Il s'appuie sur l'expérience étendue acquise par la RCAF dans l'entraînement de pilotes canadiens, des pays de l'OTAN, ou d'autres nations.

PRIOR LEARNING AND AGE IN RELATION TO PILOT PERFORMANCE

Wing Commander J.M.Brown

I would like to express my appreciation to the Medical Panel for providing equal time to Psychology in these discussions. As a psychologist, however, I would like to introduce a word of caution into your deliberations.

We in psychology have achieved a reasonable degree of success in assessing human behaviour, but I am not convinced that these assessments have been put to best use. Our stock-in-trade has been prediction and the establishment of the highest possible validity for our assessments. Prediction alone is not enough, however, and by taking some perverse satisfaction in the training failure or accident of a marginally selected pilot, in the hope that this will raise our validity coefficient by another point, we are not fulfilling our professional obligation.

A typical approach in selection research is to look for criteria which will give us higher validities. This involves an analysis of the pilot training programme to determine those areas which present the greatest difficulty for the trainee. The aim is then to obtain reliable assessments of performance in this area. The next step is to develop a measure which is related to this criterion so that the trainees who experience difficulty with that particular phase of training can be eliminated during initial selection. Once the area of training difficulty has been identified, however, surely we should first try to solve the training problem and only then revert to a selection approach if necessary.

An important argument in support of the emphasis on selection is the rapidly increasing cost of training a military pilot, a cost which must now be approaching the $200,000 mark. We often hear how much it costs to train a pilot but how many times have you heard the question: How much is a trained pilot worth? With an apparent universal shortage of pilots, this question becomes critical.

The ever-increasing demands on operational pilots by modern high performance aircraft produce ever-increasing demands on the pilot selection and training programme. This emphasis on quality is quite justified in view of the extremely high cost of aircraft accidents and the greater skill and knowledge required by the modern pilot, but too often we are asked to solve training or operational flying problems by raising selection standards.

I want to emphasize that selection is essentially a negative process which operates throughout the career of a pilot. With every assessment of his potential, flying proficiency, or medical suitability, the pilot faces the possibility of a restriction or termination of his flying career. I am looking forward to a breakthrough in assessments of temperament, perceptual skills, performance under stress, decision-making and other higher cerebral functions, but my concern is that by increasing the number of assessments

we may simply be increasing the number of reasons why a pilot should be eliminated from the system.

Ten years ago, Webb[1] reviewed the literature for studies concerned with the selection and elimination of individuals likely to have accidents. He concluded: "...we cannot reduce accidents by the selection of persons likely to have accidents on the basis of previous accident records, pertinent aptitude measures, or pertinent performance measures" (p. 145). Just as I have suggested the danger of 'selecting' ourselves right out of the pilot training business, Webb stated that the elimination of pilots on any of these criteria to reduce accident rates would mean the elimination of practically the entire flying population.

Many significant contributions have been made by "human engineers" and others in the development of pilot aids and in the standardization of instrumentation and procedures, but these have barely kept pace with intensified training programmes and the complexity of operational flying. My argument is that psychologists interested in human learning and ability can also make a positive contribution in this area.

If we are to enhance learning, reduce flying accidents, and improve the operational effectiveness of pilots, we must move on to a more positive emphasis on the modification of pilot behaviour through training. To accomplish this aim we must strive for a better understanding of the complex variables which account for the wide range of individual differences found in the assessment of pilot ability. In this regard I differ from Webb, who attributed the lack of relationship between pilot-centred measures and accidents to the homogeneity of the pilot group following intensive screening and training attrition. I submit that pilots may appear to perform routine flying tasks in a similar manner but that, in fact, they vary considerably in their capacity to cope with the stress and demands of unusual flying situations.

Although there are many who still believe that pilots are "born and not made", there is ample evidence that man's abilities are not irrevocably fixed by biological endowment. Although biological factors may fix boundaries, there is a growing body of evidence that the range of variation in performance that results from prior learning is very great indeed. I refer to the theoretical work of Ferguson[2, 3] on transfer, learning and human ability; the experimental work of Fleishman[4] on the different patterns of ability present at different stages of practice, and to the coping and developmental theory of adaptive behaviour described by Fine and Jennings[5]. These approaches all stress the importance of viewing "learning" as a developmental process. This view is also supported by the extensive experience of the RCAF in the training of various pilot groups with wide differences in cultural backgrounds and experience, including British Commonwealth countries, North Atlantic Treaty Organization (NATO) members, and more recently pilot trainees from Nigeria and Tanzania. Time does not permit a review of these pilot programmes but I can refer you to a paper by Sloan[6] on the RCAF experience with the training of NATO aircrew.

I would like to make brief reference to two RCAF studies involving the variables of prior learning and age. The first was an intensive examination of the performance of 164 pilots at a jet fighter Operational Training Unit (OTU) and a follow-up of pilot error accidents.

A [illegible] relationship between proficiency at OTU and subsequent PE accidents is shown in Table I. We are faced with the usual problem that *post hoc* we have identified a group of pilots representing 18.3% of the total group accounting for 36.4% of the accidents.

What to do? One obvious solution would be to increase training standards. The accident rate for this sample could have been reduced by more than one third by the elimination of the "pass with qualification" group at OTU. This would have raised the attrition rate from 5% to 25% at this late stage, however, and seriously reduced the operational effectiveness of the squadrons. I hope it is clear by this time that arbitrary changes to selection or training standards can be effective only with a reduction in the quantitative requirements for pilots or an increase in the number of trainees available from the manpower pool. In our present situation it appears that the only course of action is to reduce accidents by increasing proficiency.

Wide variations in experience and age were found in the sample of 164 pilots. The accident results for three distinct groups are contained in the right hand column of Table I. For ease of identification these are referred to as *"post-war tour"* (trained since World War II but with a tour as flying instructor or staff pilot before selection for fighter role), *"wartime trained"* (with a variety of flying and staff positions), and *"pipeline trained"* (those proceeding directly through training). The average ages for these groups were 27, 35, and 21 respectively, with almost no overlap. The accident rates are consistent with those reported by Zeller[7] on much larger samples, i.e., highest for the young and less experienced group, next for the oldest, and least for the middle group.

To complete the picture, a breakdown of the accident rates and proficiency of the three groups is also shown. Although the numbers are extremely small, I would like to speculate about some of the results.

Differences in proficiency and accident liability for the "post-war tour" and "wartime" pilots might be accounted for in terms of recency and relevancy of previous flying, as suggested by Zeller[6], but this explanation does not hold for the "pipeline" trained pilots. How then do we account for the marked individual differences in proficiency and accident liability for this group.

There is reason to believe that the pace of training (course length and syllabus content) may be too fast for many "pipeline" trainees. It is impractical to have an individually paced pilot programme and uneconomical to have it geared to the slowest trainees. Thus the pace is usually set for the average of the group being trained. An important implication of this situation is that those who are below the group average in aptitude or ability must progress at a rate which is not conducive to effective learning and retention. This condition produces most of the validity of our selection process, because most of our failures come from this group, but the effect on those from this group who pass is often overlooked. Although these trainees are able to meet minimum but acceptable standards, they have not had the opportunity to practice and to consolidate their learning, and thus are not fully prepared for the new learning and pace required at the next stage. This effect is cumulative from stage to stage and may account for variations in proficiency or accident liability within what should be a fairly homogeneous group.

Age was included in the title of this presentation because of the obvious relationship between age and experience. Study of either variable should not be undertaken without a consideration of the possible confounding effects of one on the other. I would like to make passing reference to a laboratory experiment[9] on perceptual-motor learning using a continuous compensatory tracking task. The design enabled the experimenter to determine the differential effects of each variable using RCAF pilots of various ages and flying experience as subjects. Clear evidence of the facilitating and interfering effects from prior learning on performance of the perceptual-motor task were demonstrated. In a separate analysis, the effects of age on performance were demonstrated with prior learning as a control variable. One finding of interest, although perhaps an obvious one, suggested that a deterioration of performance with increasing age may result largely from the effects of negative transfer (habit interference). Performance of 39 and 26 year old pilots, with the same amount of previous flying, showed no differences when transfer effects were positive, but significant differences in favour of younger pilots when the control-display relationships were changed to produce interfering effects from prior learning.

It is difficult to conceive of a learning situation in which transfer of training does not play some part. Prior learning must be regarded, therefore, as an important variable in determining the nature and amount of transfer. Because all new learning takes place in the context of habits established by all previous experience, performance on any particular flying task will be determined by the total effect of these positive and negative transfer effects. Pilots "cope" with new learning or emergency situations by psychologically putting them in the context of appropriate habits already mastered. If the prior learning is incomplete or inappropriate, the response will be inadequate The implications for pilot proficiency and accident liability are obvious.

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TABLE I

Breakdown of Air Division Pilot Error Accidents by Pilots Differing in Experience and Proficiency

Group		*Pass OTU as Outstanding*	*Middle*	*Pass OTU with Qualification*	*Total*
Post-war Tour	Accid. Free	12	6	2	20
	With Accid.	0	0	0	0
N = 20	%	0	0	0	0
Wartime	Accid. Free	16	16	9	41
	With Accid.	1	3	3	7
N = 48	%	5.9	15.8	25.0	14.6
Pipeline	Accid. Free	15	48	9	72
	With Accid.	2	15	7	24
N = 96	%	11.8	23.8	43.8	25.0
Total	Accid. Free	43	70	20	133
	With Accid.	3	18	10	31
N = 164	%	6.5	20.5	33.3	18.9

The 31 pilots were involved in a total of 33 accidents. The two pilots with two PE accidents both graduated from OTU with some qualification, one "wartime" and one "pipeline" trained. This raises to 12 the total accidents for this group.

PLASMA PHOSPHOLIPID COMPOSITION
AS A BIOCHEMICAL INDEX TO STRESS

by

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SUMMARY

Investigations of phospholipid changes in subcellular components of the livers of animals exposed to lethal levels of ionizing radiation revealed significant increases in total phospholipid in a "lysosomal-like particle" and in microsomes. Chromatographic identification of the individual phospholipid components defined the most marked changes in content following X-irradiation in the fraction identified as phosphatidyl glycerol. These changes in composition, content, as well as in P_{32} turnover in the phospholipids became evident long before there was any physiological or chemical manifestations of irradiation.

On the premise that diverse physiological reactions to stress have common chemical parameters, changes in phospholipid composition were investigated in various stress conditions using blood plasma of the human as source material. Exposure of humans to acceleration stress from head-to-foot ($+G_z$) for a time sufficient to induce grey-out or black-out significantly increased the total plasma phospholipid content by about 70%. But more marked was the fourfold increase in phosphatidyl glycerol. Centrifugation of subjects in chest-to-back positions ($+G_x$) for time periods insufficient to induce cyanosis showed no marked changes in total phospholipid, but some increase in phosphatidyl glycerol. Subjects laboring under the stress of schizophrenia gave the highest observed levels of phospholipid. In these subjects, both lecithin and sphingomyelin were outstandingly elevated compared to normals.

These data suggest that the phospholipid composition of the human blood plasma reflects the action of cerebral metabolic control factors. The resolution of these factors and the bionergetic role of phospolipids like phosphatidyl glycerol offer an investigative approach, both to biochemical recognition of biological response to stress and to a protective methodology. Appropriate studies are under way.

RESUME

L'étude des modifications en phospholipides affectant les composants subcellulaires de foies d'animaux exposés à des niveaux mortels de radiations ionisantes a révélé une augmentation significative des phospholipides totaux dans une "particule du type lysosome" et dans les microsomes. Des procédés chromatographiques appliqués aux divers éléments entrant dans la composition des phospholipides ont révélé que c'est dans le phosphatidyl-glycerol qu'apparaissent les modifications de teneur les plus importantes aprés exposition aux rayons X. Ces changements de composition, de teneur, et du taux de renouvellement du P_{32} affectant les phospholipides sont apparus avec évidence bien avant toute autre manifestation physiologique ou chimique de l'irradiation.

En partant de l'hypothèse que diverses réactions physiologiques au stress ont des paramètres chimiques communs, on a étudié les changements de composition des phospholipides dans différentes conditions de stress, en utilisant le plasma humain comme matériel de base. En exposant des sujets humains à une force d'accélération tête-pieds ($+G_z$) pendant une période suffisamment longue pour provoquer l'apparition d'un voile gris ou d'un voile noir, on a constaté une augmentation significative (environ 70%) de la teneur totale du plasma en phospholipides. Le phosphatidyl-glycerol a accusé une augmentation encore plus sensible, puisque son pourcentage s'est trouvé multiplié par quatre. Chez des sujets soumis à des essais en centrifugeuses dans la position poitrine-dos ($+G_x$) pendant un laps de temps inférieur à celui nécessaire à l'apparition d'une cyanose, on n'a constaté aucune modification sensible des phospholipides totaux, mais, par contre, une augmentation du phosphatidyl-glycerol. C'est chez les sujets travaillant sous l'emprise de la schizophrénie que l'on a observé les pourcentages de phospholipides les plus élevés. Leur taux de lécithine et de sphingomyéline était trés supérieur à la normale.

On peut conclure d'aprés ces données que la composition du plasma humain en phospholipides est directement liée à l'action des facteurs de contrôle métabolique du cerveau. La connaissance de l'action de ces facteurs et du rôle bio-énergétique de certains phospholipides tels que le phosphatidyl-glycerol constitue un instrument de recherche permettant de déterminer le processus biochimique de la réponse biologique au stress et de mettre au point des méthodes de protection. Des études à cet effet sont actuellement en cours.

PLASMA PHOSPHOLIPID COMPOSITION AS A BIOCHEMICAL INDEX TO STRESS

B. David Polis, J.J.Martorano, H.P.Schwarz, E.Polis and L.Dreisbach

Any review of experimental approaches to the problems of biological stress and fatigue can best be summarized by the quotation from Thoreau - "This is a long story, which shouldn't be long, but it will take a long time to make it short."

From a biomolecular standpoint we can define stress in terms of biological energy demand relative to its supply. Although there is considerable experimental and conceptual development in the area of biological energy generation, the mechanisms of biological energy utilization and control are largely unknown. On the premise that diverse physiological reactions to stress have common chemical parameters, we began to seek a molecular handle which might be used to probe the energetic and regulatory pathways involved in stresses like acceleration peculiar to aerospace flight. One of the few advantages of acceleration stress is that it offers a physically defined, easily reproducible challenge to the physiological organism to marshall the most effecient utilization of biological energy for survival, in the face of a decreased cellular energy supply.

The molecular changes found in the plasma of humans under stress of interest to us here really originated from work with rats.. It is well known that when the pituitary gland is removed surgically from the base of the brain of animals, a preparation is obtained that is especially sensitive to stresses like cold and to infections. These animals do not grow, they lose sexual function, and there is considerable derangement in metabolism. It was expected that these animals also would lose tolerance to acceleration stress and that by determining the hormone factors necessary to regain acceleration tolerance, the energy pathways critical for survival at high G levels might be defined. But instead of losing tolerance to acceleration stress, the rats actually gained it[1]. The curves shown in Figure 1 represent the probit of the percent survival of a rat population at 20G plotted against the log of the time. This is merely a device for converting the normal bell shaped statistical distribution curve into a straight line function so that it is easier to visualize effects and determine statistical significance of a biological event. It is apparent here that while the median survival time of a normal rat population is in the order of nine minutes, the survival time of the hypophysectomized group is increased by at least 300 percent. Conversely, when the adrenal glands of rats were excised, tolerance to acceleration was decreased[1]. Since there is an interplay between pituitary and adrenal, we at least can conclude that hormonal factors of the pituitary-adrenal axis are determining factors in the survival to acceleration stress, in addition to the cardiovascular and hemodynamic effects so frequently emphasized.

When we look at a relatively simple function related to cardiac work during high G load as shown in Figure 2, an interesting pattern difference between the heart rate of

the normal and hypophysectomized rat becomes evident. Both animals go into a shock phase with the onset of G load, characterized by a marked bradycardia. Both animals recover to a resistance plateau, but in the normal animal this is of short duration, and the heart is exhausted in about 10 minutes. The heart of the hypophysectomized rat loses its energy more slowly and survives longer. There is little difficulty in recognizing the advantageous changes for survival at high G induced by hypophysectomy. The mechanisms by which this is accomplished are somewhat more complicated. Correlations of survival or death from centrifugation with the heart rate level during the final exhaustion phase suggested an interplay between heart and brain that was mediated by hormonal factors. Thus cardiac failure obviously could be modified by cerebral regulatory hormones, and brain survival was dependent on cardiac output. Both these events emphasized the importance of cellular factors that were concerned in the generation, control and utilization of biological energy.

Most of the oxygen uptake by the cell occurs in the mitochondrion. And it is across the compartmentation membranes of this subcellular structure that the major useful energy for cellular functions must occur. There is some evidence that phospholipids play a role in these transfer reactions and for this reason we looked for some indications of a phosphorylated intermediate of energetic significance in mitochondria.

The analytical procedure used for this study is illustrated in Figure 2. Without entering into details, this represents the end result of two dimensional paper chromatography of the decylated phospholipids extracted by chloroform methanol from mitochondria. The combination of descending chromatography in phenol water acetic acid with inophoresis in pyridine-acetic acid-water permits the separation and quantitation of the individual phospholipids shown. This procedure, which represents a modification of the method of Dawson[2], made possible the study of changes in phospholipid content and composition in stress.

Figure 4 shows the turnover rate of phosphorus 32 in mitochondrial phospholipids in-vivo[3]. The first block shows that the most rapid incorporation occurs in a fraction consisting of a mixture of traces of phosphatidic acid and of phosphatidyl glycerol. The second block shows that the phosphatidyl glycerol turnover, which peaks in the first hour, is perceptibly slowed when the animal has been exposed to ionizing radiation. The third block shown the very slow turnover rate in cardiolipin. Blocks 4, 5, and 6 represent the data obtained with phosphatidyl ethanolamine, phsophatidyl choline and phosphatidyl serine. The marked incorporation rates for phosphatidyl glycerol focused our attention on this molecule.

Phosphatidyl glycerol is synthesized in the cell in a particulate fraction of the reticulo endothelial system. By density gradient centrifugation in ficoll solutions, the fraction from liver with a major content of phosphatidyl glycerol was isolated and the changes that occurred following the stress of ionizing radiation studied. The data in Table I shows that while only a small change or no change takes place in the other phospholipids cited there is at least a four-fold increase in phosphatidyl glycerol content of this particulate fraction from rat liver. Comparable changes, moreover, were also found in the phosphatidyl glycerol content of rat plasma. That these changes were related to a general stress syndrome rather than the specific stress of ionizing radiation followed from the finding of elevated levels of phosphatidyl glycerol in plasma and in liver of rats exposed to acceleration stress. Attention was directed then to possible changes in human plasma attributable to physiological stress.

The data on stress-induced changes of phosphatidyl glycerol in human plasma is summarized in Table II. The normal group of young volunteers was subjected to a haversine acceleration pattern of 10 seconds duration at 3.0 to $4.5G_z$ (head to foot) sufficient to induce gray-out or black-out in all individuals. Each subject served as his own control with blood samples taken from an arm vein before and after centrifugation. All the subjects were on a low fat diet. Every individual showed an increase in total phospholipid after acceleration, but the individual levels of control phospholipid varied sufficiently to make the mean group change non-significant. Similar effects were found for lecithin and sphingomyelin. The most definitive change occurred with phosphatidyl glycerol which showed a 3-to-4-fold increment in each individual following acceleration. These changes were significant for the series. It was interesting to note that the direction of change of cardiolipin was opposite to that found with the other components.

The next group represents the mean plasma phospholipid levels of three volunteers from Lankenau Hospital on three weeks bed rest on a low fat diet. Apparently bed rest, in itself a stress, elevated the phosphatidyl glycerol level above the normal control value and lowered the cardiolipin level. When the subjects were exposed to acceleration in G_x (chest to back) position for time periods insufficient to cause black-out, there was still a significant increase in phosphatidyl glycerol but the other phospholipids essentially were unchanged.

In a series of eight patients hospitalized with the diagnosis of schizophrenia, the total phospholipid levels are elevated above that of the normal. Here again the phosphatidyl glycerol level can be considered as significantly and uniquely different from a normal group. The other noticeable difference in the schizophrenia group is that both lecithin and sphingomyelin were elevated outstandingly compared to normals.

It is apparent then that in a number of stress states, phosphatidyl glycerol uniquely was increased out of proportion to the other phospholipids. Can we then use this molecular change as a biochemical index for physiological stress? Recalling that the labelled phosphate turnover was greatest for phosphatidyl glycerol and least for cardiolipin, let's examine the variation of the molar ratio of phosphatidyl glycerol (G) to cardiolipin (C) in the various stress conditions. (Table III).

These ratios were rounded off to the nearest whole number. Acceleration to black-out raises the G/C ratio from 1 to 6. Prolonged bed rest shows a level of 3 and centrifugation of the bed-rested subject brings the G/C ratio to 7. These subjects were reported to be very weak after their acceleration runs, even though the acceleration was chest to back and no black-out or gray-out was experienced. Schizophrenia reveals a ratio of 5, suggesting that while the G/C ratio does not diagnose the condition of schizophrenia, it does indicate that the schizophrenic brain is responding as if it were in a stress state. The last three ratios are mean values of six subjects exposed to sleep deprivation in experiments that will be detailed by Dr Squires. It was gratifying to find that before sleep deprivation, the G/C ratio was 2 corresponding, as expected, to the normal group. After sleep deprivation the G/C ratio rose to 6. The psychic changes accompanying sleep deprivation need no elaboration to emphasize a possible metabolic relationship in two stress conditions. Following sleep and recovery, the G/C molar ratio returned to 2. In this metabolic ability to recover from an elevated G/C ratio, the normal stressed subject markedly differs from the schizophrenic, leading to the speculation of a possible metabolic block of these restorative processes in schizophrenia.

Well, do we have any insight or any approach to these metabolic control factors concerned with the levels of phosphatidyl glycerol? Let's return to the experimental work with rats (Table IV). The normal rat, with a survival time of about 10 minutes at 20G, shows the same increase in total phospholipid and the same marked jump in phosphatidyl glycerol found in the human. The hypophysectomized rat has a phospholipid distribution somewhat lower than normal, but still within normal range. When the hypophysectomized rat is accelerated at 20G, it has a median survival time of 45 minutes. But the phospholipid levels of the accelerated hypophysectomized rat are lower than normal. The phosphatidyl glycerol level is decreased rather than increased, and the cardiolipin level is elevated rather than lowered. Finally, the increased acceleration tolerance of the hypophysectomized rat is accompanied by a lower G/C plasma ratio rather than a higher G/C ratio found in the less tolerant normal animal. These changes are interpreted to indicate a mobilization of phospholipid utilization, probably influenced by the absence of inhibitory pituitary hormones or pituitary activated factors, and are considered to suggest a cerebral regulatory function as implicated in the control of the metabolism of phosphatidyl glycerol.

The marked changes in plasma phosphatidyl glycerol levels in human following stress have some obvious and immediate medical applications and implications. Using the plasma molar ratio of phosphatidyl glycerol to cardiolipin as a biochemical index of stress, a a molecular bridge is attained between diverse stresses ranging from the physically induced physiological shifts of acceleration stress and the physiologic and psychologic fatigue of sleep deprivation to the psychic aberration of schizophrenia. Of even greater interest and importance from the mechanistic viewpoint of the biochemist, are the concomitant changes in phosphatidyl glycerol that take place in the liver. The liver is a major source of phospholipid synthesis. It is conceivable that stress signals referred to the brain are communicated to the liver via hormonal or neurologic pathways to cause a phospholipid dumping into the plasma. Whether the liver, or the lymph glands, or both are the source of the phospholipid dump in stress, the question of how phosphatidyl glycerol of all phospholipids is uniquely increased by anoxic and fatigue stress, the role of this molecule in energy transfer and utilization, and the mechanisms by which these occur create a new challenging problem in the bioenergetics of physiological stress.

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TABLE I

Effect of Ionizing Radiation on Phospholipids of an Isolated Liver Lysosomal Fraction

	Control	*Irradiated*
	← mg phospholipid/g protein →	
Total phospholipid	184	220
Lecithin	109	120
Cardiolipin	7	8
Phosphatidyl glycerol	3	13.9

TABLE II

Changes in Plasma Phospholipids During Stress

	Normal	*Normals Accelerated* G_z	*Bedrest*	*Bedrest Accelerated* G_x	*Schizophrenics*
	μg P	μg P	μg P	μg P	μg P
Mean total phospholipids per 100 ml plasma	← per 100 ml Plasma →				
	5032 ± 2300	5509 ± 1166	5523 ± 239	5923 ± 80	8403 ± 1330
Lecithin	2893 ± 1600	3175 ± 721	3450 ± 500	3620 ± 159	5381 ± 1400
Phosphatidyl glycerol	50 ± 17	221 ± 56	72 ± 27	137 ± 22	172 ± 57
Cardiolipin	105 ± 24	82 ± 19	71 ± 60	79 ± 61	137 ± 48
Sphingomyelin	335 ± 65	611 ± 206	457 ± 121	407 ± 95	779 ± 199

(1) Normal – 8 subjects.

(2) G_z – 4 subjects at gray out and black out.

(3) Bedrest – 3 Lankenau Hospital Volunteers – (4 subjects for total phospholipids only).

(4) G_x – 3 Lankenau Hospital volunteers – (after acceleration) G_x position. No gray out.

(5) Schizophrenics – 8 schizophrenic subjects.

TABLE III

Effect of Stress State on Molar Ratio of Phosphatidyl Glycerol to Cardiolipin

Stress State	*Molar Ratio** *Phosphatidyl Glycerol/Cardiolipin*
Normal	2
Normal accelerated G_z	7
Bed rest	3
Bed rest accelerated G_x	6
Schizophrenia	5
Pre-sleep deprivation	2
Sleep deprivation	6
Recovery	2

* A fraction of the phosphatidyl glycerol is isomerized in the deacylation procedure before chromatography and appears in the P spot. The phosphatidyl glycerol value here represents the sum of the G and P values.

TABLE IV

Effect of Hypophysectomy on the Distribution of Phospholipid in Rat Plasma After Acceleration

	Normal	*Accelerated Normal*	*Hypox*	*Accelerated Hypox*
	←	μg P/100 ml plasma		→
Total phospholipid P	4648	5341	3893	2905
Lecithin	2724	3224	2540	1778
P	84	120	41	32
Phosphatidyl Glycerol	82	131	50	38
Cardiolipin	120	118	51	81
Sphingomyelin	224	277	333	296

Normals: all from 3-4-66
- Control I pooled plasmas Rats restrained 30′
- Control II pooled plasmas Rats restrained 12½′
- Control III pooled plasmas Rates unrestrained

Accelerated Normals: from 3-4-66 Accelerated I 18 G pooled plasmas 30′
from 3-4-66 Accelerated II 18 G pooled plasmas 12½′
from 7-12-66 Accelerated Normal 19 G pooled plasmas (5 + 6, 10 + 11) 5½′

Accelerated Hypox. from 7-12-66 Pooled 2-12 19 G 36′ (approx.)

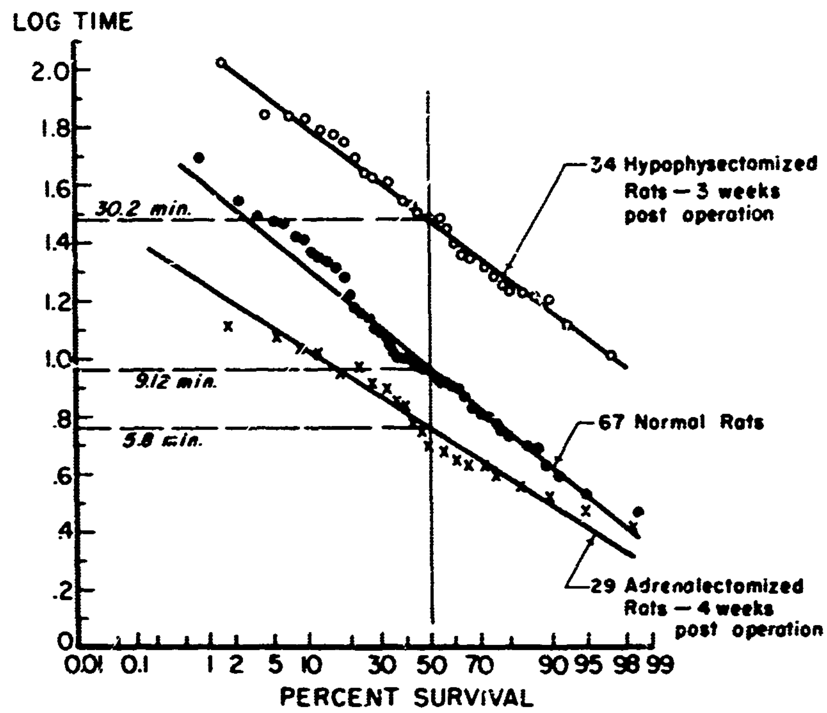

Fig. 1 Effect of hypophysectomy or adrenalectomy on the resistance of Sprague Dawley rats to acceleration at 20G.

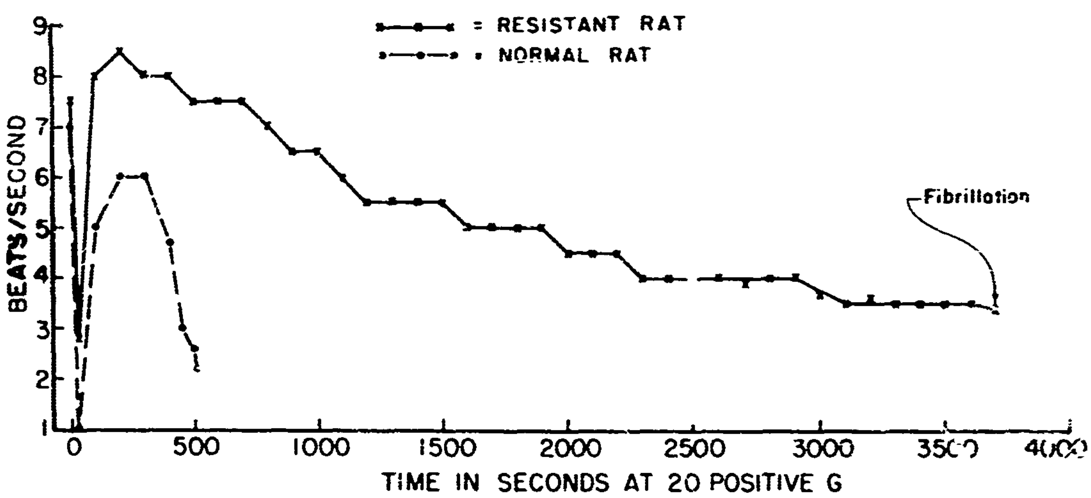

Fig. 2 Heart rate of normal and resistant Sprague Dawley rats under acceleration at 20G.

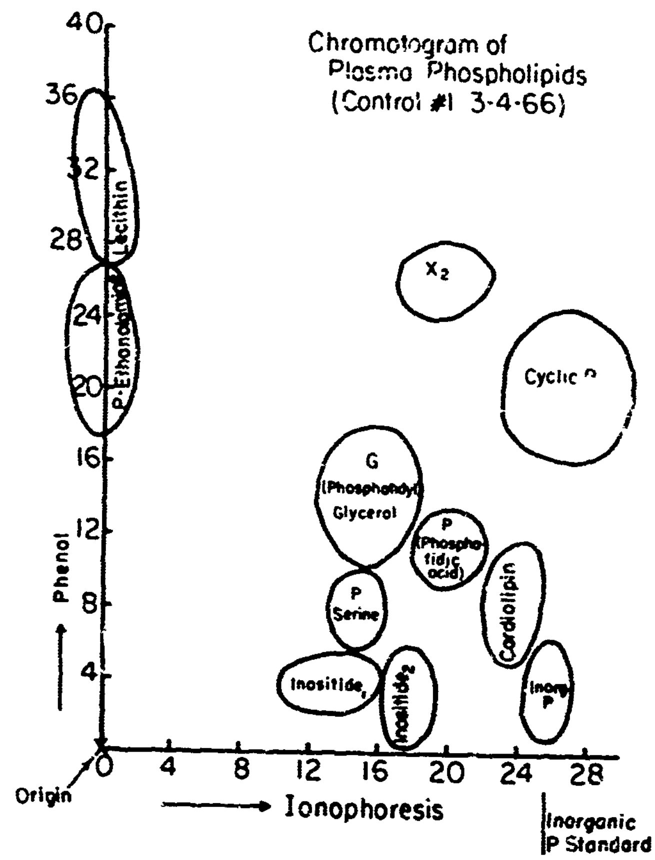

Fig.3 Chromatogram of plasma phospholipids.

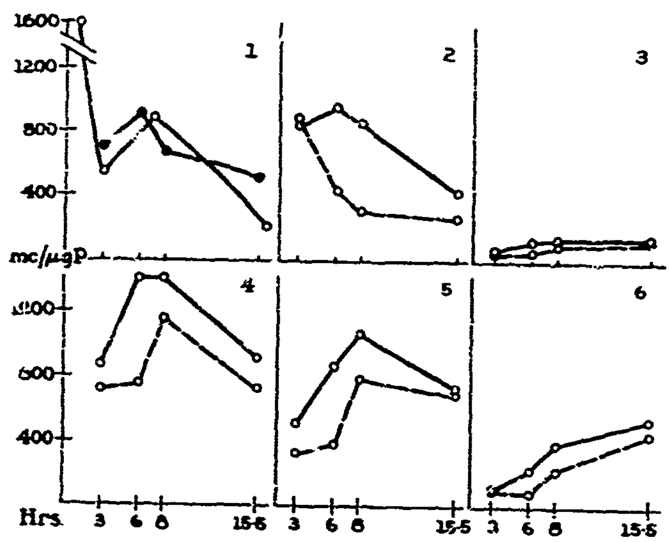

Fig.4 Turnover rate of phosphorus 32 in mitochondrial phospholipids.

THE ELECTROENCEPHALOGRAM AS A PHYSIOLOGICAL CRITERION OF PERFORMANCE

by

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SUMMARY

Indications of physiological changes within the central nervous system concomitant with psychologically measured deterioration in performance can be obtained from the electroencephalogram (EEG). Continuous monitoring of selected frequency components of the EEG has been found to provide an objective estimation of an individual's level of wakefulness as well as an evaluation of the extent and duration of his visually directed attention. Equipment designed for such studies has recently been developed in this laboratory. It is now being used in evaluating the effect of certain metabolites and drugs on sleep-walking cycles and on the level of intensity of visual attention.

RESUME

L'électroencéphalogramme permet de révéler des modifications physiologiques survenant au sein du système nerveux central et accompagnant une détérioration de la performance qui peut être mesurée psychologiquement. On s'est aperçu qu'un contrôle constant de certaines composantes de fréquence de l'électroencéphalogramme permettait d'obtenir une évaluation objective du niveau de vigilance du sujet ainsi que du degré et de la durée de son attention visuelle. Le laboratoire de l'US Naval Air Development Center a récemment mis au point un équipement propre à ces études, équipement que l'on utilise actuellement pour déterminer l'effet de certains métabolites et de certaines substances pharmaceutiques sur les cycles de sommeil et d'activité physique et sur le degré et l'intensité de l'attention visuelle.

THE ELECTROENCEPHALOGRAM AS A PHYSIOLOGICAL CRITERION OF PERFORMANCE

Russell D. Squires, M.D.

During the past few years we have been developing and testing a reliable, miniaturized, solid state, FM-FM, personal telemetry system for continuous monitoring of the electroencephalogram (EEG), the electrocardiogram, the respiration rate and tidal volume and various body temperatures. This system effectively eliminates the encumbrance of wire connections to receiving equipment. The unobstructed radius of transmission is about 300 feet.

This paper will only deal with some preliminary EEG studies obtained while testing this equipment. A single EEG recording was obtained by attaching with bentonite paste three silver wire mesh electrodes along the midline of the unshaven scalp. One active electrode was placed over the vertex, the second one inch forward of the inion, and the third, the indifferent or ground electrode, half way between the two active electrodes. At the receiving station the EEG signal was simultaneously recorded on magnetic tape and a direct writing oscillograph. It was also subjected to frequency analysis.

The analyzer can be divided into four basic units: (1) automatic signal level control; (2) band pass filters; (3) a switching system; and (4) a rectification circuit. The automatic signal level control, or more properly, automatic gain control prevents the amplitude variations of the EEG signal from exceeding 5 volts and thereby prevents blocking in the amplifier-filter system. The band pass filters each have width of one cycle per second and a number of filters can be placed in parallel by the switching circuit, thus permitting the division of the EEG frequency spectrum into a number of discrete band widths. The voltage outputs of the parallelled activated filters comprising each discrete band width are converted to directed current by the rectification circuit and recorded on a direct writing oscillograph.

This analyzer provides a nearly "real time" analysis. Maximum rectified voltage response for a frequency change is attained at the fifth consecutive cycle. Therefore, at one cycle per second, there is a five second delay and at ten cycles per second, 0.5 second delay, etc.

One obvious advantage of this sort of analysis is that changes in the frequency components of the EEG can be resolved at recorder speeds as slow as a few millimeters a minute. This readily permits comparison of the preceding changes in the voltage outputs of the selected frequency bands for time periods of one-half hour or more depending on how much paper is exposed to view on the recorder. An example of the voltage output of the band pass filters is shown in Figure 1. The band width labeled beta (β) is 20-25 c/s, alpha (α) is 10-15 c/s, theta (θ) 6-7 c/s, and delta (δ) 1-4 c/s. The subject from whom this record was taken had had little sleep the night before and had worked until he was permitted to fall asleep in the late afternoon. At the beginning of this record his eyes

had been closed for about 15 minutes. The decreasing beta and alpha activity, as well as the increasing theta and delta activity, indicated the subject was falling asleep. Approximately 9 minutes from the beginning of this record the subject stated that he had been suddenly aroused by a frightening dream. Whereupon the beta and alpha activity increased while theta and delta activity decreased. The EEG changes, however, indicated the subject again promptly fell asleep. One-half hour later he stated that he was fully awakened from a sound sleep by a sudden loud noise and the EEG frequency changes again indicated arousal. This sort of record shows that even a relatively inexperienced electroencephalographer can distinguish between sleep and wakefulness.

Figure 2 illustrates another type of experiment. Here the subject was requested to do various tasks. Some of them required that he use his eyes; others did not. Initially the subject was merely asked to sit and listen to instructions. He was then instructed to stare at an oscilloscopic display of the voltage output of his alpha band and see if he could depress the alpha voltage by staring at it. After the alpha voltage had decreased, he was instructed to close his eyes. There was an immediate increase in alpha voltage. A marked increase in theta voltage also occurred. He was later asked how he felt with his eyes closed and told us he was afraid something unpleasant might be done to him while his eyes were closed. This may explain the marked increase in theta voltage. Up to this time there had been very little change in either the beta or delta bands. No change would ordinarily be expected in the delta band unless the subject fell asleep. The subject was next instructed to study a weather report and informed that at some future time he would be requested to recall and tell us what he had read. While reading the report, there was a marked increase in beta activity while the alpha and theta activity decreased. When requested to recall and orally report what he had read, beta activity showed a transient decrease, alpha activity increased and there was a slight increase in theta activity. He was again asked to sit quietly and listen to further instructions. During the written mathematics test, beta activity steadily increased and alpha activity decreased. He was next given a ball bearing puzzle and instructed to maneuver the two ball bearings into the eye sockets of the face drawn on the puzzle. One of the ball bearings was asymmetrical and therefore very difficult to maneuver. This subject showed only a slight increase in theta activity. Other subjects, obviously frustrated by the asymmetrical bearing, often showed a greater increase in theta activity. Beta activity decreased slightly during this task and alpha suppression remained maximal. In the next task he was given a miniature pin ball machine, informed of the highest score made by the subjects preceding him and instructed to try to beat it. The beta activity tended to increase slightly but finally attained a lower level than occurred during the ball bearing puzzle task. There was a slight increase in theta activity toward the end of the task. When the subject was informed that this was his final task and was instructed to close his eyes, beta activity underwent a further decrease, alpha activity increased markedly and theta activity decreased to the lowest level. The increased height of the alpha response and the further slight reduction of theta activity were probably due to relief of apprehension and frustration.

This is a typical record. Tasks which required visual attention depressed alpha activity and tended to increase beta activity. Such changes did not appear to be directly related to the quality of the subject's performance Subjects who apparently tried hard but performed poorly showed changes similar to subjects who also tried hard and performed well. During periods of obvious frustration as, for example, when the task presented difficulties or when the subject stated he had felt apprehensive, theta activity sometimes increased. These preliminary studies suggest that this type of

monitoring would separate periods of intense visual concentration from periods of less intense visual concentration, and further suggest that periods of frustration and/or apprehension could also be identified.

Figure 3 shows the integrated voltage output for one-minute periods for ten alternating periods each of eyes-open and eyes-closed. The white columns indicate eyes open and the black columns eyes closed. The point on the ordinate indicated by 0 is the average of the 10 eyes-closed periods, and the X is the average of the 10 eyes-open periods. For each frequency band shown the maximum voltage output for each of the 10 periods of eyes-open or eyes-closed was divided into the voltage output of the other 9 periods. Thus each period is graphed in proportion to the maximum voltage output. This partially explains why the beta output voltage which is approximately 1/20 of the maximum alpha output voltage appears to be always higher. If this had not been done, the changes in beta activity presented on the same scale as alpha activity would have been barely visible. The band widths for alpha, beta, and theta are the same as in the previous experiment. The subject was also instructed to stare at an oscilloscopic tracing of his alpha voltage during eyes-open.

The object of this experiment was to test whether 36 hours of sleep deprivation had any effect on the EEG. During the presleep deprivation test, eyes-closed alpha activity always increased when compared to the immediately preceding eyes-open period and conversely, the eyes-closed beta and theta activities always decreased when compared to the immediately preceding eyes-open period. Such was not always the case after sleep deprivation. There was sometimes little if any change in alpha activity when eyes were closed and once alpha activity actually increased when the eyes were opened. The relative differences in the average eyes-open and eyes-closed beta and theta activities were decreased and the average eyes-closed beta and theta activities increased during sleep deprivation.

In the postsleep deprivation test when the subject felt rested, the EEG frequency pattern became very nearly the same as in the presleep deprivation state.

Table I summarizes the EEG changes produced by sleep deprivation for five different subjects. Average changes in level of activity of 10 percent or less were considered insignificant. The upper part of the table shows the average percent change in relative alpha, beta and theta activities when sleep deprivation was compared to presleep deprivation during eyes-open and eyes-closed. When eyes were open, the average alpha activity was increased and the average theta activity was decreased. There was no change in average beta activity. During eyes-closed, the average change in individual alpha activity varies, but there was no change when the five subjects were averaged together; and there was a tendency for average beta activity to increase with the exception of subject number five. The theta activity tended to similarly increase with the exception of subject number three.

When sleep deprivation was compared to postsleep deprivation in the lower part of Table I, i.e. after sleep, the average alpha activity, except for the first subject, decreased and the average theta activity increased for all subjects. There was again no change in average beta activity. Thus after sleep and rest, the eyes-open EEG pattern returned to the presleep deprivation pattern. The average individual eyes-open alpha, beta, and theta activities were variable and the average change for the five subjects was unchanged. Thus it would appear that on the average, one could not distinguish between the eyes-closed EEG pattern of a sleep-deprived subject and a rested subject. When,

however, the eyes are open and when using the type of EEG analysis described here, an increasing amount of alpha and a decreasing amount of theta activity would suggest that the subject was becoming sleepy and/or fatigued.

Dr Polis will report during these same meetings that plasma phosphatidyl glycerol concentration is increased during stressful situations such as acceleration and enforced bed rest. The G + P fractions in Table II represent the plasma phosphatidyl glycerol concentration which was also increased by sleep deprivation and decreased toward the presleep concentration following sleep. We have to date completed the analysis for only one of the 6 subjects tested.

Other work now in progress in our laboratories employing certain chemicals and drugs strongly suggest that we can identify at least one portion of the brain involved in the stress response, namely the preoptic region of the forebrain.

The preliminary studies briefly described in this paper represent a serious effort directed toward establishing an interdisciplinary approach to study of the problems of human stress and fatigue, and their relationship to performance.

TABLE I

Changes in EEG After Sleep Deprivation

(Sleep Deprivation)/(Pre-Sleep Deprivation), % Change							
Subject	*Alpha*	*Beta*	*Theta*	*Subject*	*Alpha*	*Beta*	*Theta*
	Eyes Open				Eyes Closed		
1	+21	0	-26	1	-22	+24	+117
2	+24	+5	-36	2	-5	+19	+43
3	+6	+10	-22	3	-8	+25	(-15)
4	+54	+2	-15	4	(+20)	+6	+6
5	+29	+1	-3	5	-9	(-12)	+82
Average	+27	+4	-20	Average	(-5)	+12	+37
(Sleep Deprivation)/(Post Sleep Deprivation), % Change							
Subject	*Alpha*	*Beta*	*Theta*	*Subject*	*Alpha*	*Beta*	*Theta*
	Eyes Open				Eyes Closed		
1	(+20)	+1	+30	1	(+24)	-25	-25
2	-40	-3	+41	2	-26	-14	-11
3	-31	-9	+60	3	(+8)	-18	+20
4	-36	+8	+12	4	-3	(+10)	0
5	-38	+3	+13	5	-17	(+13)	+47
Average	-25	0	+31	Average	-3	-7	+6

TABLE II

	Pre-Sleep Deprivation		*Sleep Deprivation*		*Post-Sleep Deprivation (Rest)*	
TOTAL μg P / 100 ml PLASMA	7500 μg		7067 μg		7100 μg	
	μg P / 100 ml	% of Total P	μg P / 100 ml	% of Total P	μg P / 100 ml	% of Total P
LECITHIN	4029.4	38.7	3951.0	30.1	3967.7	30.1
P	52.8	0.5	129.3	1.0	72.4	0.5
G	41.7	0.4	138.6	1.1	47.6	0.4
G + P	94.5		267.9		120.0	
CARDIOLIPIN	75.5	0.7	64.4	0.5	97.8	0.7

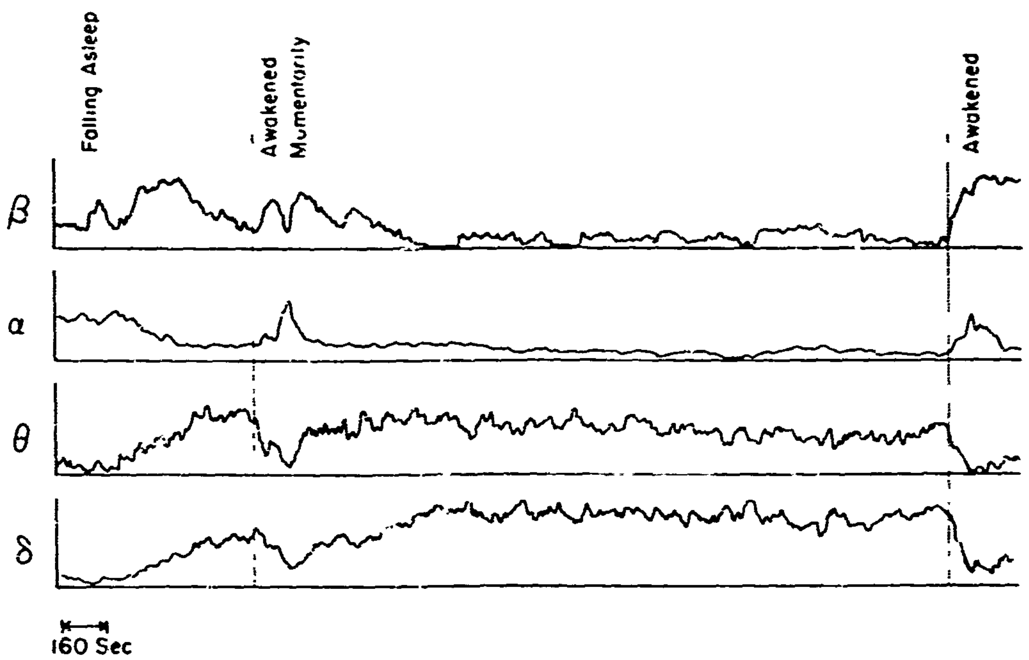
Falling Asleep
Awakened Momentarily
Awakened
β
α
θ
δ
160 Sec

Figure 1

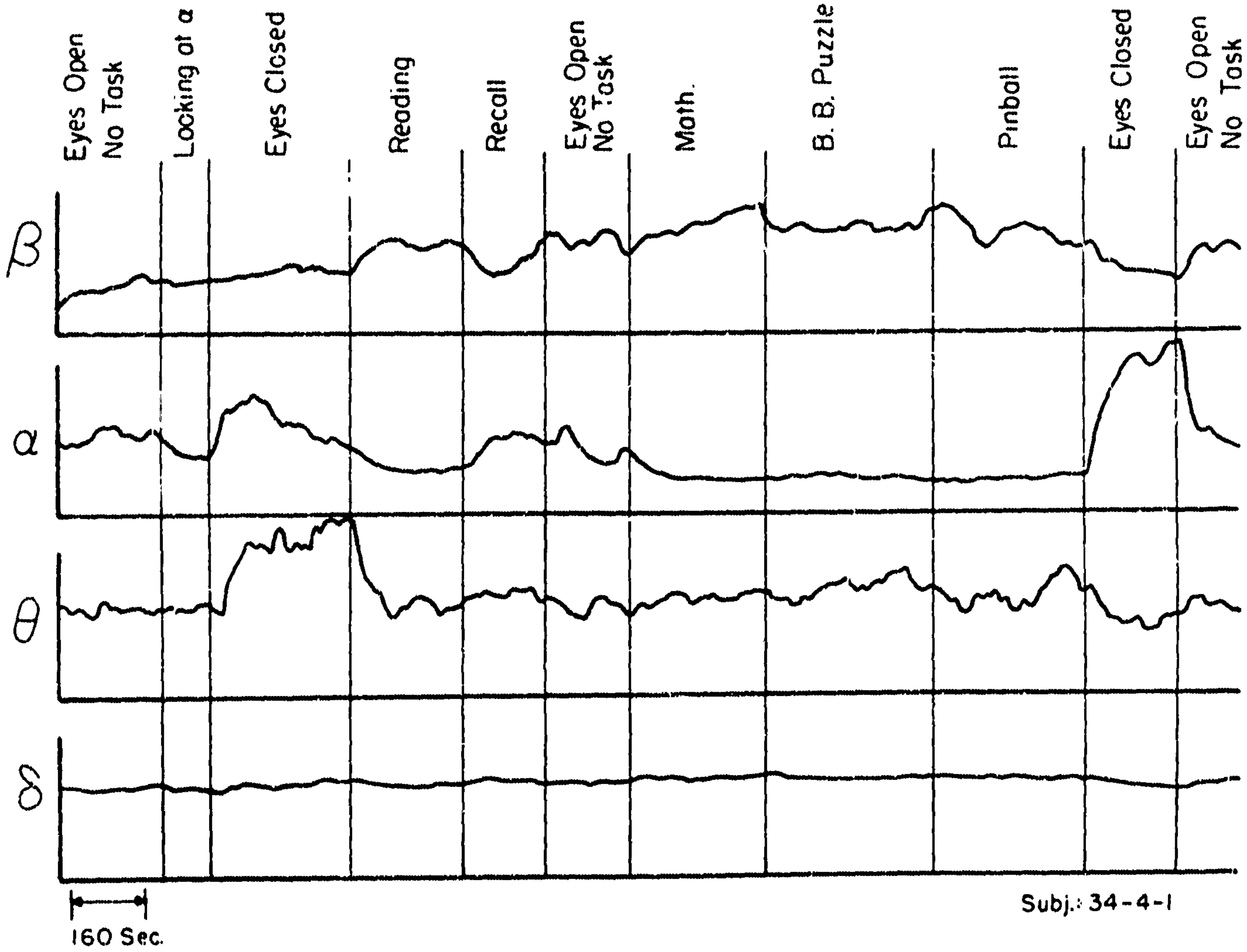
Eyes Open
No Task
Locking at α
Eyes Closed
Reading
Recall
Eyes Open
No Task
Math.
B. B. Puzzle
Pinball
Eyes Closed
Eyes Open
No Task
β
α
θ
δ
160 Sec.
Subj.: 34-4-1

Figure 2

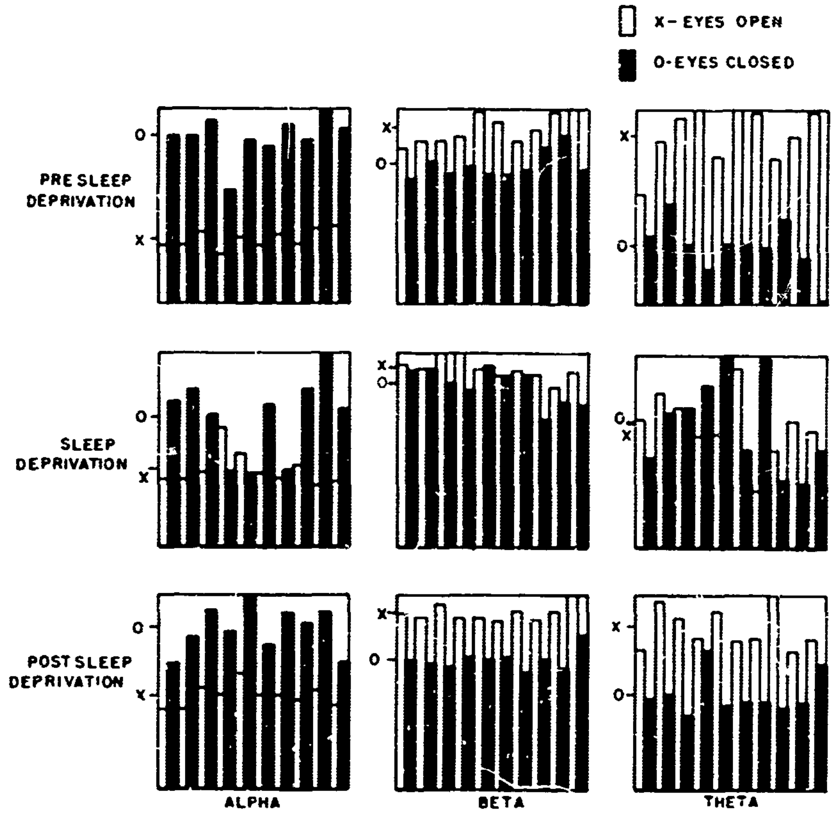
X- EYES OPEN
O-EYES CLOSED
PRE SLEEP DEPRIVATION
SLEEP DEPRIVATION
POST SLEEP DEPRIVATION
ALPHA
BETA
THETA

Figure 3

THE USE OF PSYCHOPHYSIOLOGICAL MEASURES IN THE ASSESSMENT OF OPERATOR EFFORT

by

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SUMMARY

The level of activity in physiological systems which are under the control of the autonomic and somatic nervous system, may be considered to reflect, inter alia, the mental and physical "effort" demanded by the task.

As the operator attempts to maintain control to a prescribed standard, variations in task dynamics, display or output characteristics may not be revealed by measures of performance on the basic task, although the loads imposed by the task differ. Attempts have been made to assess operator load using both psychological and physiological techniques. In psychological terms one method has been to use a secondary task. Such a technique is founded upon an assumption of a fixed performance capacity of the human operator. It is argued by the experimenter that differences in the demand placed upon the subject by variations in the experimental task will be shown by the level of performance the subject is able to produce on the secondary task whilst maintaining the required level of performance on the experimental task. A second method of measuring operator "effort" is provided by recording physiological activity (e.g. heart rate, skin resistance, muscle activity, respiratory rate and ventilation).

The result of experiments on subjects who performed simple closed sequence control tasks, and those of greater complexity provided by the simulated and actual flying task, will be described. The limitations of psychophysiological measures in behavioural studies will also be discussed.

RESUME

On peut considérer que le niveau d'activité des systèmes physiologiques sous la dépendance du système nerveux autonome et somatique reflète, entre autres, l'"effort" physique et mental exigé par la tâche à accomplir.

L'opérateur s'efforçant de maintenir un niveau de contrôle donné, les variations qui affectent la dynamique de la tâche, l'information ou les caractéristiques de sortie peuvent ne pas être révélées par les mesures de capacité fonctionnelle dans l'exécution de la tâche de base, bien que les charges imposées par cette tâche diffèrent. On s'est efforcé d'évaluer la charge à laquelle est soumis l'opérateur en recourant à des techniques à la fois psychologiques et physiologiques. Dans le domaine psychologique, l'une des méthodes employées a été de faire exécuter une tâche secondaire. Cette technique est fondée sur l'hypothèse qu'un opérateur humain possède une capacité de rendement fonctionnel déterminée. L'expérimentateur part du principe que les différences de niveaux d'effort imposés au sujet, différences dues aux variations de la tâche expérimentale, seront reflétées par le niveau de rendement fonctionnel du même sujet tandis qu'il accomplit la tâche secondaire tout en maintenant le niveau de rendement exigé pour la tâche expérimentale. Pour mesurer l'"effort" de l'opératuer, il existe une deuxième méthode qui consiste à enregistrer l'activité physiologique de ce dernier (par ex. sa fréquence cardiaque, sa résistance cutanée, son activité musculaire, sa fréquence respiratoire, et sa ventilation).

Les auteurs décriront les résultats d'expériences consistant à faire exécuter des tâches simples de commande en séquence fermée, et d'autres plus complexes comme celles à accomplir en vol réel ou simulé. Ils exposeront également les limitations des mesures psychophysiologiques dans les études de comportement.

THE USE OF PSYCHOPHYSIOLOGICAL MEASURES IN THE ASSESSMENT OF OPERATOR EFFORT

A. J. Benson and J. M. Rolfe

1. INTRODUCTION

In seeking to measure human performance the experimenter is faced with the question of deciding exactly what measures to use and what interpretation he may place upon any data obtained from these measures. Assuming that the subject plays an active part in the data recording process, there are four sources from which an experimenter can obtain measures of the operator's performance. These are:

(i) Measurement of the operator's performance on the task under investigation (the primary task).

(ii) The operator's subjective assessment of his performance on the primary task.

(iii) Measurement of the operator's response to one or more additional tasks performed concurrently with the primary task.

(iv) The operator's physiological response in the task situation.

When, however, the object of the experiment is to measure the effort required to perform a task, there are a number of basic objections to relying entirely on either primary task performance or subjective assessments.

Although he may have to work harder - exert greater effort - to achieve the required level of performance, measures of performance may, of themselves, not reveal the change in task load until the operator is working to the limit of his capacity. Conversely improvements to a system, which would be expected to reduce task load, may not be accompanied by a commensurate melioration of performance because an acceptable standard is achieved with the expenditure of less mental or physical effort.

One of the principal disadvantages attendant on the use of subjective assessments is that alteration in task load can modify the subject's appreciation of the quality of his performance. For example, an operator may report that his performance has improved although it may have been severely degraded by the imposed experimental conditions[1].

Thus neither objective nor subjective assessments of primary task performance allow unequivocal statements to be made about task load or synallagmatically, operator effort. Yet some estimate of these variables is required, for they are the principal determinants of the range of situations in which the operator will be able to maintain his performance, and of his ability to perform additional tasks. It is in providing the solution of these problems that the use of secondary task and of physiological techniques are of value.

2. THE SECONDARY TASK

The use of the secondary task technique is based on the concept that the human operator's ability to handle information is limited by a central decision mechanism, which must be allowed a finite time to process one stimulus-response before a second can be accepted[2,3,4,5].

Experimental investigations of the operator as a single decision channel system have, in the main, relied upon situations where the subject was presented with discrete stimuli sequences of known brief-time separations from one another[6,7,8,9,10]. Unfortunately the real world can rarely be precisely defined, for many tasks are continuous and have temporal relationships of a more stochastic nature. In an attempt to bring together the theoretical studies of the human operator and the applied areas of psychological research, Broadbent[11] elaborated a model of the single channel operator which conformed to the data obtained from his own and other workers' researches into multiple task performance using auditory signals. Likewise Poulton[12], as the theoretical basis for his own use of a secondary task, stated that "there is a limit to the rate at which an operator can deal with information" - in other words he has a limited channel capacity. "When the demands of the primary and subsidiary tasks together exceed this limit, errors must occur". Similar views have also been expressed by Garvey and Henson[13], and by Knowles[14], who compared the operator to a time division multiplex communication system using a single channel to transmit messages from several sources to several destinations.

Thus it may be argued that performance on a standard secondary task, which is independent of the primary task, provides a measure of the demands of the primary task and an indication of the operator's spare capacity. From a review of contemporary psychological literature[15] it was apparent that secondary tasks have been used in four types of experimental studies. These were:

(i) Comparison of alternative methods of performing the same operation[12,13,16].

(ii) Investigations of the changes in work load during the various phases of a complex task[17,18,19,20,21].

(iii) The study of operator learning in relation to the modification of the capacity available to deal with other tasks as the primary task was learned[22,23,24].

(iv) Investigation of the human operator's ability to handle information from a variety of sources[25,26].

This technique has been of value in studies of human factors in aeronautical research. In the United States various control display systems for the X-15 vehicle were evaluated in a secondary task situation[27], and the same technique used to study orbital and lunar landing vehicle systems[28,29]. In the United Kingdom secondary tasks have been used at the Institute of Aviation Medicine in the assessment of aircraft instrument display systems and in-flight environments[30,31].

One such investigation arose from the need to evaluate the presentation of dynamic information by purely digital displays. An initial experiment showed no significant difference in subjects' performance on a compensatory tracking task when a purely digital altimeter display was used and when this was combined with a scale and pointer display. It was concluded that parity of performance on the two displays were obtained at the

expense of increased effort by the subjects when the purely digital display was used. In order to investigate this hypothesis a further experiment was carried out in which a second task, which took the form of a two choice, light acknowledging, operation was introduced into the experimental situation. The subjects were instructed to attend to the secondary task only when they felt they could do so without affecting performance on the primary task. Because of these instructions it was considered that performance on the secondary task would provide a relative indication of the effort demanded by the two displays employed in the primary task.

It was found that, whereas performance on the primary task was unaffected by the variations in the display (Table I) performance on the secondary, light acknowledging, task was significantly affected (Table II). Subjects failed to acknowledge twice as many lights when tracking with the purely digital display as when tracking with the combined digital and scale and pointer display. Thus it was concluded that parity of performance obtained with the two primary task displays was indeed achieved as the result of increased effort on the part of the subjects when the purely digital display was employed.

In a later experiment, performance of subjects was studied during a task which required them to undertake a series of settings using a digital display. Again a secondary light responding task was employed, but instead of measuring the number of signals not acknowledged, the response time to each individual stimulus was recorded The decision to intensify the sensitivity of the recording was made because it was considered important to be able to examine the demands of the primary task during very brief time periods. The results obtained from this experiment showed that subjects' response times on the secondary task were not only related to the psychomotor components of the tasks, but that information gathering and processing activities, prior to an overt motor response, also had an effect upon secondary task behaviour

It was therefore argued that if the extra demand was in the gathering of information from the visual display, the replacement of the visual secondary task by one in the auditory modality would reduce the interference between primary and secondary tasks However, if the constraint was in the central processing of the information, then the separation of the sensory channels for primary and secondary tasks would have little effect. When tested experimentally, the latter result was found to occur, for both visual and auditory presentation of the secondary task resulted in the same increase in response time in the period immediately preceding the initiation of a motor response. This finding suggested that the secondary task was sensitive to central data processing activities, and could indicate the periods during which changes in task load associated with information processing could influence the subjects' performance capability.

Other experimenters have experienced difficulties in distinguishing alternative methods of performing the same tasks when the load imposed upon the subject was one which involved conceptual rather than perceptual motor activities[29]. However, there is evidence to suggest that a suitable secondary task can be extremely useful in demonstrating the variations in the ease of anticipation and timing of responses during the performance of a complex skilled task[32,33]. Yet, the secondary task is only of value in such situations if it is capable of measuring changes in performance over short time periods which are commensurate with the time taken to carry out decisions and actions on the primary task.

The value of secondary task measures in situations such as those described above seems undeniable. However, it is essential that the choice and design of secondary tasks should be given adequate consideration. It appears to be most important to bear in mind that a secondary task should satisfy the following criteria:

(a) The operating procedure of the task can be easily learned and capable of being left and restarted frequently.

(b) The task should at all times demand part of the subject's conscious attention if it is to be performed successfully.

(c) The task should not interfere directly with the primary task.

(d) The operator should find it impossible to perform the secondary task perfectly in a control condition when working at the secondary task alone.

(e) The task should be such that the subject can be given clear unambiguous instructions about the relative priority of primary and secondary task

Having stated these requirements, it is necessary to express some caution in relation to the value of secondary tasks in complex systems evaluation. It is of particular importance to note that, despite the clarity with which an experimenter instructs the subject about the priority of the primary over the secondary task, it has been found that performance of the primary task suffers at the expense of the secondary task. Such was the result obtained in the experiments described above. One explanation of this interaction between primary and secondary task is that the experimenter unwittingly introduces a task induced stress. Indeed, the increased incidence of omissions, errors, and approximation, features characteristic of behaviour under stress[34], suggest that is so.

Another aspect of behaviour which would explain the unwanted performance decrement has been mentioned earlier, namely, the subject's inability, under stress, to qualitatively assess his own performance. One explanation for this is that the decrement in performance which occurs on the primary task takes place because the subject changes his criterion of what is an acceptable performance In other words, his threshold for error is unconsciously readjusted. It has been shown elsewhere that subjects' error threshold need not be constant and that it can change with the demands and complexity of the task In several studies of fatigue[35,36,37] a lowering of the acceptable error criterion has been noted, while it has also been shown[33] that the somewhat different stress imposed by an increased work load can also engender an increase in the limen of detectable error. In consequence, it may be argued that when task load is increased by the introduction of a secondary task the subject's criterion of acceptable performance on the primary task is degraded, so that he would fail to appreciate that he was not achieving the same quality of performance on the primary task as when it was performed in the absence of the secondary task.

The interference with primary task performance by the secondary task is a serious disadvantage to the use of this technique in the flight environment. In many of the phases of flight in which an assessment of work load is desirable, e.g. take-off, landing, high-speed low-level flight, the addition of a secondary task may degrade aircraft control to such an extent that the life of the pilot and other aircrew may be jeopardized. A salutary warning is provided by the simulator studies of Goldsmith, Sherman and Vitale[39] who found that the inclusion of a secondary task in a simulated terrain

following task resulted in subjects being unable to continue performing the simulated task and the secondary task at the same time. Consequently, for airborne and perhaps also simulator studies, the secondary task appears to be severely limited. Some other measure must therefore be sought which can yield data comparable to that provided by secondary task performance measures; it is for this reason that an examination of the value of physiological measures has been undertaken.

3. PHYSIOLOGICAL MEASURES

It is well established that the activity in physiological systems of the body is related to the behavioural state. Though Golla[40] was the first to suggest that the level of physiological acitivity was a function of "effort", with the advent of the concept of an arousal continuum[51,52] it is now more popular to consider physiological activity as an indicant of "arousal" or "activation" within the central nervous system. However, the generalisation elaborated by Golla, namely that physiological activity is increased by either "mental" or "physical" "effort", is paralleled in the arousal theory by the precept that arousal is increased both by the mental demands made by the task and by the intensity of physical stimuli. Thus it may be argued that task load is a determinant of the level of arousal, which in turn is manifest in the physiological responses of the individual. It must, however be recognised that, apart from the inherent difficulty of the task, the penalty imposed by the failure to perform to a particular standard can play an important, and at times dominant, role in the regulation of arousal in a given task situation. For example: arousal engendered by loss of control when flying on instruments in a simulator is likely to be very much less than that which would occur in flight, because in the former situation the life of the operator, and perhaps others, is not in jeopardy.

Despite the prolixity of physiological changes which have been shown to accompany alterations in the behavioural state there is no one measure which is a direct indicant of arousal. It may be thought that the electroencephalogram, being a manifestation of the electrical activity of the brain, should provide the least ambiguous information about the level of arousal, but in the majority of control tasks where the loop is closed by a visual display, the relationship between EEG activity and arousal is covert and is only to be made manifest by complex analytical procedures. Accordingly it is necessary to study other physiological variables which, by virtue of the central control exercised through the somatic and autonomic nervous system, serve as indicants of arousal. It is not proposed here to discuss all the physiological manifestations of alterations in the behavioural state, but rather to point out those which may be studied in individuals during flight or when performing a task which is a partial or complete simulation of that which is carried out in flight. The choice of the physiological variable to be studied is in part determined by the recording techniques which have to be employed, for it is important, particularly in the flight environment, that the attachments of sensors and transducers to the subject does not interfere with his performance of the task. Not only should the subject be free of additional physical impediment, but should also not suffer pain, discomfort, or be distracted by the recording techniques employed. Within these limitations the physiological measures which would appear to be of value in the assessment of task load may be summarised as follows:

AUTONOMIC			
	Cardiovascular	Heart Rate	
		Blood Pressure	
		Vasomotor Tone	Skin and Muscle (Plethysmography)
			Blood Flow
			Skin Temperature
	Sudomotor	Sweat Production	Skin Resistance (GSR and Basal and Potential Measures)
	Respiratory	Respiratory Rate	
		Ventilation	Alveolar (End Tidal) CO_2 tension
SOMATIC		Somatic muscle activity	Grip pressure
		(Integrated EMG)	

In a group of individuals, alteration in task load is associated with a characteristic change in the mean level of activity in any one of these measures, the magnitude of which is correlated with the increment in task difficulty. However, because of the idiosyncratic nature of the physiological response, in any one individual such a correlation may or may not be present according to the physiological variable which is studied. From the work of Lacey, Bateman and van Lehn[43] and Schnore[44] it is known that the pattern of an individual's physiological response to an alteration of arousal is stereotyped. For example, one person may show a large change in heart rate and muscle activity but little sudomotor response, in another a comparable change in arousal may evoke a large fall in skin resistance but little change in heart rate.

These studies of individual response specificity and inter-individual differences are of methodological importance in the design of experiment in which physiological measures are to be used in the assessment of task load. They draw attention, firstly, to the importance of comparing the effect of differing experimental conditions within each subject rather than between subject groups, and secondly, to the advantages of employing several physiological measures rather than one. If only one physiological measure is employed (say heart rate), then because of inter-subject response specificity, the assessment of the alteration in arousal produced by task variables is likely to be disproportionately influenced by those subjects who exhibit large changes in the particular physiological system which is studied. The use in combination of several physiological measures allows a more reliable comparison of task load to be made. Furthermore, in experimental studies in which intra-subject comparison can be made, it increases sensitivity, so that differences between task conditions which were not manifest in any one physiological measure, can be resolved when the measures are combined. This is illustrated by the results of an experiment described earlier in which subjects performed a compensatory tracking task, with and without a secondary task, in which two altimeter displays were compared. Whereas heart rate, skin resistance, muscle tension in left forearm and calf muscles (muscle groups which were not involved in the control task) and ventilation, all showed a significantly greater increment in activity above the resting level when the secondary task was performed, none of these measures showed a significant difference between the two altimeter displays. However, when the measures were combined it was apparent that a significantly greater increment in physiological activity occurred

with the counter display alone, than when this was used in conjunction with a scale and pointer instrument (Table III). Thus in an experimental situation in which performance scores on the primary task did not differentiate between the two displays, measures of physiological activity revealed that one display made a greater demand on the operator than the other.

The conclusion to be drawn is that, in situations where intra-subject comparison of the physiological response to a change in task variable is possible, and when several physiological measures rather than a single one, can be employed, then it is likely that relatively small differences in task load can be detected. It is not suggested that physiological measures offer a technique of greater sensitivity than is provided by detailed measurement of performance on the primary or secondary task, but in certain situations (e.g., pilot/aircraft control) where it is undesirable to introduce a secondary task and quantification of overall performance presents considerable difficulties, measures of physiological activity may allow a relative, if not absolute, assessment of task load to be made.

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TABLE I

Mean Time in Seconds, Per Four-Minute Period, During Which Error Was Less Than ±150 ft

One-Task		Two-Tasks	
Counter only	Counter + Pointer	Counter only	Counter + Pointer
227.3	231.2	207.6	227.3

TABLE II

Mean Number of Lights Not Acknowledged Per Four-Minute Period

Second Task only	Second Task with Counter + Pointer	Second Task with Counter only
1.5	5.5	11.5

TABLE III

Sign Test Applied to Task-Rest Increments, in Order to Compare Magnitude of Change Produced by the Two Displays. (C = Counter Only, CP = Counter and Pointer Display)

	One-Task		*Two-Tasks*	
	C > CP	C < CP	C > CP	C < CP
Heart Rate	8	8	9	6
Skin Resistance	9	7	13	3
EMG Arm	7	8	8	7
EMG Leg	9	6	10	6
Respiratory Rate	10	5	9	7
Ventilation	8	6	8	6
End Tidal PCO_2	11	3	11	4
	62	44	68	39
	Difference N.S.		Difference Sig. P = 0.005	

INFLUENCE OF MILD HYPOXIA ON VISUAL PERCEPTION DURING POST-ROTATORY OPTICAL NYSTAGMUS

by

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SUMMARY

The authors have investigated the effects of gaze fixation upon targets, exposed for short periods, on duration and characteristics of ocular post-rotatory nystagmus, and its influence on visual perception characters.

Visual fixation has been reported to reduce nystagmus amplitude, and duration, as well as slow-phase angular velocity, whereas the frequency of oscillations is increased.

Nystagmus modifies targets perception with a light increase of errors of perception, and of angular, and spatial evaluation. These changes, however, are scarcely significant.

Experiments carried out in the same subjects, submitted to mild hypoxia, have resulted in a worsening effect.

RESUME

Les auteurs ont étudié les effets, sur la durée et les caractéristiques du nystagmus oculaire post-rotatoire, de la fixation du regard sur des objectifs visuels, pendant de courtes périodes; ils ont également examiné son influence sur les caractéristiques de la perception visuelle.

Ils ont observé que la fixation visuelle réduit l'amplitude et la durée du nystagmus, ainsi que la vitesse angulaire de la phase lente, tandis que la fréquence des oscillations s'accroît.

Le nystagmus modifie la perception des objectifs visuels, en ce sens qu'il augmente légèrement les erreurs de perception et d'évaluation angulaire et spatiale. Ces modifications sont toutefois minimes.

Ces expériences ont également été effectuées sur les mêmes sujets, mais cette fois en état de légère hypoxie; on a pu constater une aggravation des effets observés.

INFLUENCE OF MILD HYPOXIA ON VISUAL PERCEPTION DURING POST-ROTATORY OPTICAL NYSTAGMUS

Aristide Scano, Giorgio Mazza, Rocco Caporale

1. INTRODUCTION

The problem of orientation in difficult flight condition, and therefore of the correct and prompt perception of cockpit instruments during the effects of abnormal labyrinthine excitations, continues to be of great aeromedical interest.

In particular, the extra-physiological stimulation of the semicircular canals provokes a series of perceptions which may be contradictory (apparent rotation of objects in the visual field and apparent rotation of the body itself) and in contrast with information deriving from other sense receptors (especially the visual one). Under these conditions the pilot may use his reason to check erroneous perceptions, or he may become disoriented.

In the first case he calculates which is the "true" information and which the "false", giving preference to the former. The information which we call "true" is that deriving from the instruments the pilot has available in the cockpit, and which enables him to orientate himself correctly (electric and magnetic compasses, altimeters, variometers, turn-and-bank indicators, artificial horizon, radar etc.). The information that we call "false" is that deriving from the sense organs and which do not correspond to the actual situation.

Therefore, disorientation may result

(i) from lack or inaccuracy of instrument information (due to instrument failure).

(ii) from the pilot's inability to discriminate between "true" and "false" information.

Obviously, in the presence of contradictory information, the decisive part in achieving a judgment based on reality will be played by exercise, self-discipline, emotional control, the inhibition of certain instinctive reactions, and trust in the instrument. In other words, information deriving from the vestibular organ under extra-physiological stimulation – even if it is in contrast with other sensorial data – may not necessarily produce disorientation, as long as the pilot succeeds in checking the "false" information and formulating a judgment of reality based exclusively (or almost exclusively) on "true" information.

Armstrong[1] said, quite rightly, in 1952, "Most of the time taken by the pilot to learn instrumental flight is taken up by his learning to disregard false sensations, and no-one can learn instrumental flight unless he is convinced that sensations are always wrong when they don't agree with the instruments".

Of special interest is the problem of the pilot's being able to perceive correctly "true" information available through visual function, even in the presence of optical nystagmus elicited by angular acceleration. In fact, if one could demonstrate the impossibility of reading and interpreting visual data from any instrument during a nystagmus, "true" information on which the pilot must base his orientation would be missing.

According to studies carried out by Melvill Jones[2], some of which were in actual flight, the fixing of the gaze is notably hindered because of nystagmus and consequent counter-rolling reaction of the eyeballs during certain flight manoeuvres.

Arslan[3] and Bergstedt[4] state that nystagmus from rotary stimulation is modified by simultaneous fixing of the gaze. The effects are: reduction of the amplitude, decrease of angular velocity values in the slow phase, decrease of duration, increase in frequency of oscillations. The qualitative characteristics of nystagmus would be also modified during gaze fixation (McLay et al., 1957). Therefore, ocular fixing of the cockpit instruments by the pilot should act on nystagmus so as to favour the interpretation of visual information, especially the reduction of the amplitude and the velocity of the slow phase.

Useller and Algranti[5] confirmed that the fixing of the gaze reduced the intensity of nystagmus: they studied the behaviour of a group of pilots being submitted to high-speed rotation.

Another important factor in attenuating nystagmus seems to be the intensity with which the instruments are lit. In fact, Megighian[6] observed that an intensely luminous stimulus (400 lux) attenuated post-rotatory nystagmus, while a comparatively feeble luminosity (30 lux) had no such effect.

The problem is further complicated in actual flight when a subject undergoes a moderate hypoxic condition, which might occur through a failure in an oxygen inhalator or through the pilot's own lack of discipline or inexperience. In this connection, it is interesting to note that coordinated ocular movements (such as in reading) become less accurate under hypoxia; they slow down and are sometimes shaken by nystagmoid oscillations[7,8]. As regards the specific effects of hypoxia on nystagmus, earlier researches by Gellhorn and Spiesman[9] carried out with the technique of caloric stimulation, would seem to have shown that only a considerable degree of hypoxia (O_2 concentration below 10% for a protracted period) was able to modify the characteristics of nystagmus. In our laboratory, Caproale and Terrana[10], submitting healthy male subjects to the breathing of 8% O_2 and 92% N_2 mixtures for 15 minutes, observed an increase in the number of oscillations per minute, and of the amplitude and duration of post-rotatory nystagmus. It therefore seems of interest to investigate (a) the possibility of perceiving correctly and rapidly the information obtainable from instrument reading on the part of subjects presenting a nystagmus caused by angular acceleration, (b) the influence of moderate hypoxia on the same perceptive phenomena.

2. EXPERIMENTAL TECHNIQUE

A first series of researches was carried out on thirty pilots between 24 and 48 years of age, with active flight experience on both civil and military aircraft of from three to thirty years.

Visual, auditive, and labyrinthine functions, checked at the time of the tests, were found within prescribed standards laid down for pilot fitness.

This investigation was aimed at taking a quantitative sample of the ability to recognize visual data supplied by panel flight instrument simulators during post-rotatory nystagmus, and were carried out - always in the morning and in a dark and silent environment - using a tachistoscope controlled electrically and a Toennies-type rotating chair. The tachistoscope was placed at a distance of 1 metre from the eyes of the subject being examined. The tachistoscopic images had a luminosity level of about 3 lux (read at 10 cm from the protecting glass of the window of the apparatus) with exposure of 0.1 sec. The exposure time chosen was very short so that, while allowing a normal visual perceptive process, it would induce in the subject a considerable attentive effort even in conditions of rest, and which would none the less cause a certain number of errors, in order to obtain data which could be compared with those derived from tests carried out during nystagmus. The level of illumination was minimum, although sufficient for a satisfactory visual perception, so that it could not exert any specific inhibitory effect on nystagmus.

The visual messages consisted of images (5 x 5 cm) representing schematically, on a black background, two kinds of information from on-board instruments. The former consisted of two lines of different colours (yellow and white), one acting as a horizontal base and the other incident to it at angles varying between 90° to 0°. When the lines were parallel, the white one might be over or under the yellow one. This type of test is similar to the indications given by an artificial horizon (Fig.1). The latter type of test consisted of a horizontal yellow line divided into five equal lengths by four white notches.

A red vertical arrow might occupy from time to time any one of the five spaces. This test is analogous to horizontal instrument reading, such as in magnetic compass, direction indicator, etc. (Fig.2).

These tachistoscopic images were presented in two series each consisting of three images of each type.

All the subjects were tested according to the following method:

(i) Clockwise or anti-clockwise rotatory stimulation with acceleration of 1.5°/sec^2 up to a constant speed of 90°/sec for ten rotations, followed by abrupt deceleration.

(ii) Measurement of duration of post-rotatory nystagmus through direct observation, using Bartels glasses.

(iii) Instruction of the subject as to the manner of test and presentation of two samples of tachistoscope images.

(iv) Presentation of the first series of images at rest, with a rhythm of one every 5 sec.

(v) Rotatory stimulation of the same characteristics as before in conditions of complete darkness, and presentation of the second series of tachistoscopic images.

The presentation started 2 sec after the stopping of the chair, to allow fixing of the gaze and ocular accommodation, and proceeded at the rate of 1 image every 5 sec.

Each time the subject referred, by voice, to the characteristics of the tachistogram perceived; for the first type he gave the value in degrees of the angle of incidence of the two lines, or whether the white line was above or below the yellow, in the case of the lines being parallel; for the second type he indicated the position of the red arrow.

Measuring of the duration of nystagmus with the preliminary rotation test led to the conclusion that mean time of duration of nystagmus in the conditions described here was thirty seconds. Therefore the number of tachistoscopic images and the rate of their presentation during the second rotation test were such as to coincide with the entire duration of the nystagmus. Lastly, during some tests, an electro-nystagmogram in bi-temporal lead was recorded.

In the second series of investigations, dealing with the effects of hypoxia, tests were still carried out during the morning and in the same environment, on 19 points with experience of flight corresponding to that of the first group, from 24 to 48 years of age, and on 19 subjects not pilots (technicians, medical assistants, applicants for service in the Air Force) aged between 19 and 43. In order to have data directly applicable to practical flying, two actual flight instruments were used for the test - an altimeter and a clock; these were also exposed for a very short time. Furthermore, the deceleration was somewhat more rapidly applied, to increase the disturbing effect.

The subjects were first examined to establish that their visual, additive and labyrinthine functions were normal, and they were indoctrinated in plain te ms in the task they were expected to perform. They then carried out a preliminary binocular reading of a test-dial placed at a distance of 140 cm and lit by two lamps of a total of 80 watts for 0.3 sec, controlled by a time-switch. The two dials, a Collsman type altimeter (CA.M.5760 Salmoiraghi) for the pilots and a black-dialled clock with luminous figures and hands for the non-pilots (both having equal diameters) were placed about 4 cm apart in a box painted with opaque black, with an opening 18 x 18 cm on the observer's side (Fig.3). Two different dials were used, although bearing in mind the inconvenience this caused, owing to the difficulty experienced by non-pilots in reading an altimeter, noted during the first tests.

After the initial reading of the instrument chosen, the experimenter changed the position of the hands or needle, unseen by the subject, and began to administer normal air through the moughpiece using a normal nose clip. A second reading was than made, after which the subject, already seated on the Toennies chair, was subjected to an angular acceleration of $2^{o}/sec^{2}$ up to a maximum speed of $180^{o}/sec$. This remained constant for 3 minutes and was followed by abrupt deceleration, with the subject stopped facing the test-dial, the location of which was shown by a weak light over it. Two seconds after the chair stopped, the third reading was made, as before.

Unknown to the subject, a tap connected to a container of 11% O_2 and 89% N_2 mixture was opened, to determine an 84 mmHg $P_{I_{O_2}}$ corresponding to a height of 5000 metres (16,400 ft). A very moderate degree of hypoxia was expressly chosen because higher values produce in themselves sensorial and perceptive changes, so as to interfere considerably with the phenomenon under study and, as already mentioned, they provoke unquestionable effects on the characteristics of nystagmus. After 3 or 10 minutes of

hypoxia a fourth reading was made at any time after previous change of position of the hands or needle.

The subject was then submitted to a second rotatory stimulation of the labyrinth, and after stopping he carried out the fifth reading during nystagmus and in hypoxic condition.

From the beginning of breathing through the mouthpiece, the following data were recorded: pulmonary ventilation by means of a dry-type gas meter, respiratory and heart rate, in order to give information on respiratory and cardiac responses to hypoxia in single subjects.

3. RESULTS OF THE EXPERIMENT AND CONCLUSIONS

Before setting out the results of the two series of experiments, let us say that the nystagmographic recordings made on part of the subjects have confirmed what is already known about nystagmus, and that is that the fixing of the gaze and an effort of concentration determine modifications of post-rotatory nystagmus, and that these modifications consist of reduction of amplitude, reduction of duration, increase of frequency and reduction of angular velocity in the slow phase.

For analysis of perceptive ability, account has been taken of the errors made by subjects during the tests. These errors have been conventionally classified as follows: errors of perception (characterized by failure to identify the tachistoscopic image at all), and errors of evaluation (represented by inaccuracies in describing the specific characteristics of the image).

The latter have been divided in their turn into "errors of angular evaluation" (determined by the difference between the size of the actual and perceived angles) and "errors of spatial evaluation" (shown by the incorrect topographic location of the arrow and the parallel lines).

In computing the errors, for those of perception and those of spatial evaluation, the phenomenon has been considered qualitatively, while for those of angular evaluation a quantitative calculation has been made, totalling the degrees of difference between the actual angle and that perceived in the six tachistograms of each series. Where the subject failed to perceive the image presented, if this belonged to the group composed of figures involving angles, a conventional error of 30° was ascribed in computing errors of angular variation. Comparison of test results carried out in conditions of rest and those during nystagmus have given the following evidence (see Table I):

(i) *Errors of Perception:*

Out of thirty subjects in a total of 180 tachistoscopic tests, 5.5% errors resulted from the preliminary test and 8.8% during post-rotatory nystagmus. Further, 7 subjects made a greater number of errors in the second test, 3 in the first and 6 an equal number in the two tests. The errors were made by 10 subjects in the preliminary test and by 13 subjects during post-rotatory nystagmus.

(ii) *Errors of Evaluation:*

(a) Errors of angular evaluation. all subjects made errors in the two tests; 14 made greater errors in the second test; 13 in the first and only 3 made errors of the

same degree in both tests. Altogether, the average error of each subject, expressed in degrees, was 31.8° in the first test and 33.7° in the second.

(b) Errors of spatial evaluation: as in the preceding case, all subjects made errors in one of the two tests: 11 a greater number in the second, 12 in the first and 7 an equal number in the two tests.

From the results given here it is apparent that the subjects examined made errors of interpretation of the visual message during post-rotatory nystagmus; however, the frequency and size of the errors were not greatly different from those made in the absence of vestibular stimulation.

The only element which can be deduced is a relative frequency of errors characterized by failure to perceive the image in the test carried out during post-nystagmus. But, even in these cases, the errors did not appear to be of great quantitative significance, as their incidence was 5.5% in the first test and 8.8% in the second. This slight hindrance may be ascribed to the very short time of exposure of the image presented (0.1 sec) which in some cases may well have coincided with a rapid ocular nystagmic excursion, whose duration, during the fixing of the gaze, has about the same value (1/12 - 1/10 sec).

The equal frequency of errors noted in the two tests seems to agree with the observations referred to above, according to which the fixing of the gaze and the attentive concentration of the subject seems to play a remarkable part in attenuating the amplitude and duration of provoked nystagmus.

This first series of results enables us to state that nystagmus, elicited by a stimulation of the type and intensity adopted by us, is not such a condition as to limit significantly perceptive and visual abilities, and even less the interpretation of images. In other words, one can suppose that a pilot, subjected to uniformly increasing angular acceleration, is able to absorb the "true" information given by his flight instruments.

The relative increase in overall errors of perception (understood as the inability of the subject to give any qualitative or quantitative character to the image) seems to be put into relation to contemporaneity of exposure of the image with a rapid oscillation of ocular nystagmus.

The results of the second series of tests are summarized in Tables II and III (total numbers of correct and incorrect readings of the clock by non-pilots and of the altimeter by pilots) in which percentages are also given.

From the examination of reported data, some considerations can be drawn.

The first one, based on a comparison between the data relative to pilots and non-pilots, concerns the notable homogeneity of the responses in the three experimental conditions (post-rotatory nystagmus, moderate hypoxia, and nystagmus in hypoxia). Indeed, the subjects of both groups gave, during nystagmus, only a slight, but appreciable, increase of wrong readings, no significant variation under hypoxia alone, and a definite increase of the ratio (wrong readings)/(correct readings) during nystagmus in hypoxia.

In this case the disturbing effect appears more severe in non-pilots than in pilots (79% E/21% C – 58% E/42% C respectively).

It seems that two collateral observations should be stressed, of psychological and ergonomic interest, concerning the effect of believing one is in state of hypoxia, upon the accuracy of reading and the time necessary for the correct reading of an altimeter of the type we used. In fact, almost all the subjects of the two groups performed better in the first reading, made before applying the mouthpiece (general average 80% correct values to 20% incorrect), than in the second, carried out with the mouthpiece applied and in the erroneous belief that they were not breathing normal air (63% correct values and 37% incorrect). Furthermore, 12 pilots out of 19 were able to read accurately the first three figures of the altimeter in normal conditions (thousands, hundreds and tens of feet) in 0.3 sec. Of the non-pilots, 15 out of 19 gave an accurate first reading of the clock (hours, tens of minutes, minutes) in the same time.

In conclusion, from the whole of our researches it seems that the following conclusions may be drawn:

(i) Visual perception of indicators and instruments, presented for a brief period, is possible during post-rotatory nystagmus in the experimental conditions provided, although the readings are notably less accurate than in normal conditions.

(ii) The effect of moderate hypoxia on this perception is practically negligible in most subjects.

(iii) The perception and recognition of visual information of the same type are, in most subjects, considerably hindered by the combined action of nystagmus and hypoxia.

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TABLE I

Subject	Age	Years of Flight	*Errors of Perception Tests*		*Errors of Evaluation*			
					Angular Tests		*Spatial Tests*	
			1st	*2nd*	*1st*	*2nd*	*1st*	*2nd*
1	35	13	0	0	20°	20°	1	1
2	31	10	0	0	10°	15°	0	1
3	27	8	0	0	10°	20°	0	2
4	34	11	0	2	30°	15°	3	2
5	27	6	1	1	60°	60°	2	2
6	39	5	1	1	85°	95°	2	1
7	35	13	1	2	45°	65°	2	0
8	37	11	0	1	20°	35°	1	2
9	26	3	0	0	25°	20°	1	2
10	26	6	0	0	45°	5°	2	0
11	33	13	0	1	15°	40°	1	1
12	30	9	0	0	20°	5°	1	2
13	30	10	0	0	35°	45°	0	1
14	36	13	0	0	65°	40°	0	2
15	35	11	1	1	60°	40°	2	1
16	33	14	1	0	40°	50°	1	0
17	35	10	0	1	10°	40°	3	1
18	31	7	0	0	15°	10°	2	3
19	48	30	1	1	40°	30°	1	1
20	28	7	1	1	40°	40°	1	2
21	27	9	1	0	45°	50°	2	0
22	25	5	0	1	25°	40°	1	0
23	30	4	1	1	45°	50°	0	0
24	33	9	0	0	15°	5°	0	0
25	36	15	0	0	5°	40°	1	0
26	24	6	0	2	25°	65°	2	1
27	41	12	0	0	20°	5°	1	1
28	27	5	0	0	25°	40°	0	1
29	36	12	1	0	40°	10°	1	1
30	33	12	0	0	20°	15°	2	0
Totals	970	299	10	16	955°	1010°	36	33
Mean and percentage values	32.3	9.9	5.5 (%)	8.8 (%)	31.8°	33.7°	1.2	1.1

TABLE II

Correct (C) Erroneous (E) Readings of Test-Clock (Non-Pilots)

		Air				Hypoxia (11.1% O_2)			
		Before rotation		After rotation		Before rotation		After rotation	
		Partial sum	Total and percentage	Partial	Total	Partial	Total	Partial	Total
Group 1 Subjects 1-11 (2 min hypoxia)	(a) Breathing freely	C: 9 8 8 E: 2 3 3	C: 25 (76%) E: 8 (24%)						
	(b) Breathing through mouthpiece	C: 8 9 5 E: 3 2 6	C: 22 (57%) E: 11 (33%)	C: 6 8 5 E: 5 3 6	C: 19 (58%) E: 14 (42%)	C: 8 9 7 E: 3 2 4	C: 24 (73%) E: 9 (27%)	C: 4 3 3 E: 7 8 8	C: 10 (30%) E: 23 (70%)
Group 2 Subjects 12-19 (10 min hypoxia)	(a) Breathing freely	C: 8 8 7 E: 0.0 1	C: 23 (96%) E: 1 (4%)						
	(b) Breathing through mouthpiece	C: 5 7 4 E: 3 1 4	C: 16 (67%) E: 8 (33%)	C: 5 4 2 E: 3 4 6	C: 11 (46%) E: 13 (54%)	C: 6 5 3 E: 2 5 3	C: 14 (58%) E: 10 (42%)	C: 0 2 1 E: 8 6 7	C: 3 (12%) E: 21 (88%)

NOTE: The three figures under "partial sum" represent: (i) the reading of hours
(ii) the reading of minutes marked on clock dial (3 min)
(iii) the estimated reading of min at 5 min intervals by interpolation (see Figure 3)

Under "Total" the values are reported as a whole

TABLE III

Correct (C) and Erroneous (E) Readings of Altimeter (Pilots)

		Air				*Hypoxia (11.1% O_2)*			
		Before rotation		*After rotation*		*Before rotation*		*After rotation*	
		Partial sum	*Total and percentage*	*Partial*	*Total*	*Partial*	*Total*	*Partial*	*Total*
Group 1 Subjects 1-15 (3 min hypoxia)	(a) Breathing freely	C: 11 13 10	C: 34 (76%)						
		E: 4 2 5	E: 11 (24%)						
	(b) Breathing through mouthpiece	C: 11 10 7	C: 28 (62%)	C: 7 10 4	C: 21 (47%)	C: 12 11 9	C: 32 (71%)	C: 6 7 6	C: 19 (42%)
		E: 4 5 8	E: 17 (38%)	E: 8 5 11	E: 24 (53%)	E: 3 4 6	E: 13 (29%)	E: 9 8 9	E: 26 (58%)
Group 2 Subjects 12-19 (10 min hypoxia)	(a) Breathing freely	C: 4 3 2	C: 9 (75%)						
		E: 0 1 2	E: 3 (25%)						
	(b) Breathing through mouthpiece	C: 3 3 1	C: 9 (58%)	C: 2 3 1	C: 6 (50%)	C: 3 4 2	C: 9 (75%)	C: 2 1 2	C: 5 (42%)
		E: 1 1 3	E: 5 (42%)	E: 2 1 3	E: 6 (50%)	E: 1 0 2	E: 3 (25%)	E: 2 3 2	E: 7 (58%)

NOTE: The three figures under "partial sum" represent:
(i) the reading of thousands of feet
(ii) the reading of hundreds of feet
(iii) The reading of ten feet (see Figure 3, in which the needle indicating ten thousand feet has been omitted).

Under total the values are reported as a whole